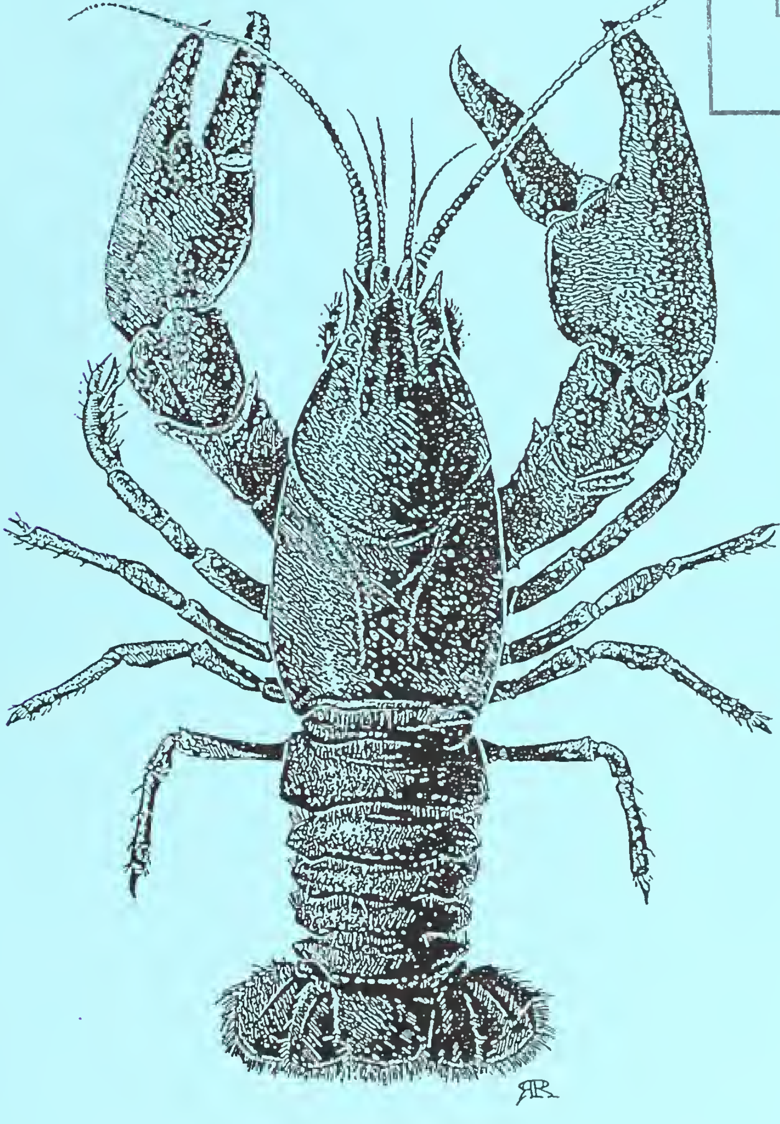
DRAFT RECOVERY PLAN
for the
SHASTA CRAYFISH
(*Pacifasticus fortis*)



U. S. FISH AND WILDLIFE SERVICE

SEPTEMBER 1997

DRAFT RECOVERY PLAN

for the

SHASTA CRAYFISH
(*Pacifastacus fortis*)

Prepared for

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

Approved: ______________________________
Regional Director, U.S. Fish and Wildlife Service

Date: ______________________________

DISCLAIMER

Recovery plans delineate reasonable actions that are believed to be required to recover and protect listed species. Plans are published by the U.S. Fish and Wildlife Service, sometimes prepared with the assistance of recovery teams, contractors, State agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Costs indicated for task implementation and/or time for achievement of recovery are estimates and subject to change. Recovery plans do not necessarily represent the views or the official positions or approval of any individuals or agencies involved in the plan, other than the U.S. Fish and Wildlife Service. They represent the official position of the U.S. Fish and Wildlife Service **only** after they have been signed by the Regional Director or Director as **approved**. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery tasks.

Literature citation should read as follows:

U.S. Fish and Wildlife Service. 1997. Draft recovery plan for the Shasta crayfish (*Pacifastacus fortis*). U.S. Fish and Wildlife Service, Portland, Oregon. 143 pp.

Additional copies may be purchased from:

Fish and Wildlife Reference Service
5430 Grosvenor Lane, Suite 110
Bethesda, Maryland 20814
Telephone: (301) 492-6403 or
1 (800) 582-3421

The fee for plans may vary depending on the number of pages.

ACKNOWLEDGMENTS

The draft of this recovery plan was prepared by Maria J. Ellis of the Department of Biology, Universities of Michigan, Ann Arbor, Michigan for the U.S. Fish and Wildlife Service's Sacramento Field Office, Sacramento, California. This plan was prepared under contract with the California Department of Fish and Game Inland Fisheries Division Endangered Species Project.

The *Pacifastacus fortis* illustration by Randy Schmieder used on the cover was reprinted from *Life on the Edge* courtesy of Biosystems Books and Randy Schmieder (© R. Randy Schmieder).

Field work conducted between July 1990–October 1994 was funded by Pacific Gas and Electric Company (PG&E) as part of the relicensing process for the Pit 1 Hydroelectric Project and the Hat Creek 1 and 2 Hydroelectric Project. The use of PG&E's data in this report is very gratefully acknowledged. Although unpublished, PG&E annually submits a report of all findings to the U.S. Fish and Wildlife Service (Service) and California Department of Fish and Game (CDFG). Data from 1993–1995, which were not included in the Pit 1 Report (Ellis and Hesseldenz 1993) are summarized in the Annual Reports for those years (Ellis 1994a, 1995, and 1996a). Housing was supplied by PG&E. The breadth and thoroughness of these surveys would not have been possible without the support of PG&E, in particular David R. Longanecker.

Robert Daniels provided many helpful discussions, as well as providing access to his field notes and other unpublished data. Larry Eng and Darlene McGriff also provided insight and access to their field notes and data. Jeff Cook provided assistance in the preparation of this plan. This manuscript was improved by comments and suggestions from John Brode, Ann Chrisney, Jeff Cook, Susan Ellis, Terry Healy, Mike Rode, Don Weidlein, and Lynn Wixom.

Shasta crayfish research, preliminary restoration, additional surveys conducted in November 1994 and in 1995, and the writing of this draft plan were funded under Contract No. FG3071IF with CDFG through Federal Grant Section 6 appropriations from the Service to CDFG. The support and help of Susan Ellis and Lynn Wixom of the CDFG Inland Fisheries Division Endangered Species Project and Kevin Stubbs, Kristi Young, and Ann Chrisney of the Service is gratefully acknowledged. Shirley Lipa, CDFG Inland Fisheries Division Contract Coordinator, managed the contractual paperwork necessary for this study to begin and proceed.

Field assistance was provided by Jeffrey D. Cook (1993–1996), Michael W. Orr (1991–1992), Glenn S. Yoshioka (1991), Jeanine M. Bayus (1994–1995), Chip O'Brien (1991–1992), Terry Powers (1992), Tom F. Hesseldenz (1990–1994), David R. Longanecker (1994), Craig Summers (1992–1993), Katherine R. Neblett (1994), Dustin Lindler (1993), Keith F. Ellis (1993), Tamara A. Shepherd (1994), Arthur McCoy (1992), Brian Barr (1994) and Jack Moore (1991). Field work in 1990–1991 was conducted in coordination with Theo Light (1990–1991), Christopher A. Myrick (1991), and Jay Clarke (1990), who were supervised by Dr. Don Erman at University of California Berkeley under contract with California Department of Fish and Game.

Surveys at Thousand Springs, Spring Creek, Lava Creek, Rising River, Rising River Lake, and some portions of the Fall River and Hat Creek would not have been possible without the permission and generous assistance given by the landowners and their managers.

Aquatic and riparian survey data were digitized by Hammon, Jensen, Wallen and Associates, Inc. Data analysis of the GIS database was conducted by Carol Neishi of PG&E Building and Land Services GIS.

Numerous conversations with long-time resident Leland Kerns provided valuable history and insight that broadened the depth and scope of this document. Les Draper and Thelma Shiplett also provided historical information that improved the document. The help of all of these people is gratefully acknowledged.

EXECUTIVE SUMMARY

Current Status: The Shasta crayfish (*Pacifastacus fortis*) is federally and State listed as endangered. Its distribution is limited to the midsections of the Pit River drainage, primarily the Fall River and Hat Creek subdrainages in Shasta County, California. This species' distribution is tied to the distribution of lava cobbles and boulders originating in the volcanic geology of the Modoc Plateau. Overall, Shasta crayfish populations have low abundance and fragmented distribution with migration and genetic exchange between populations limited by hydroelectric development and habitat loss. The limits of its geographic distribution appear to have changed little over time. Currently, there are seven populations of Shasta crayfish ranging in size from approximately fewer than 50 to 5,000.

Habitat Requirements and Limiting Factors: Shasta crayfish primarily live in cool, clear, spring-fed headwaters that are characterized by clean volcanic cobbles and boulders on top of sand or gravel. The volcanic cobble and boulders are essential habitat components because they provide protective cover for the crayfish. The main threats to Shasta crayfish include: major land reclamation, water diversion projects, and the introduction of nonnative species of crayfish and fishes.

Objective: The primary objective of this plan is to stabilize and protect existing populations so that Shasta crayfish may be reclassified as a threatened species and ultimately delisted.

Criteria for Downlisting:

1. The major subpopulations within five Shasta crayfish populations that are currently free of nonnative crayfish species (i.e., upper Fall River, Spring Creek, upper Lava Creek, upper Tule River, Rising River) are protected to ensure they remain isolated from nonnative crayfish species, especially signal crayfish.

2. The Crystal Lake population and the Sucker Springs Creek subpopulation (Pit River population) are protected and stabilized by eliminating, reducing, or managing signal crayfish.

3. Signal crayfish are eradicated in lower Lava Creek, so that Shasta crayfish are once again free of signal crayfish throughout the entire Lava Creek subdrainage.

4. The major subpopulations of the five populations that are free of nonnative crayfish and the Crystal Lake and Sucker Springs Creek populations are stable (i.e., self-sustaining and comprising representatives of all age classes) with population sizes that are stable (e.g., upper Fall River, Spring Creek, and Rising River Lake outflow channel) or increasing (e.g., Lava Creek, upper Tule River, Crystal Lake, and Sucker Springs Creek) over a 5-year period.

5. The major subpopulations in each of the seven Shasta crayfish populations are protected from disturbances related to land use practices.

Criteria for Recovery (Delisting):

1. Nonnative species, in particular signal crayfish, have been eliminated, reduced, or managed in all Shasta crayfish subpopulations, so that they no longer threaten the continued existence of Shasta crayfish at these sites.

2. All Shasta crayfish subpopulations are stable (i.e., self-sustaining and comprising representatives of all age classes) with population sizes that are increasing over a 5-year period.

Actions Needed:

1. Protect Shasta crayfish populations by eradicating or preventing invasions by nonnative crayfish, restoring habitat, and eliminating impacts from land management practices.
2. Determine the status, distribution, and relative abundance of Shasta crayfish in the mainstem of the Pit River.
3. Conduct research on the ecology, behavior, and pathology of Shasta crayfish.
4. Monitor and assess Shasta crayfish populations.
5. Develop effective watershed and ecosystem management plans for all drainages supporting Shasta crayfish populations.
6. Provide public education on Shasta crayfish.

Costs: approximately $4,570,000

Date of Delisting: 2012

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. Brief Overview

The continued existence of the Shasta crayfish (*Pacifastacus fortis)*, the only extant (existing) species of crayfish endemic (native) to California, is at risk. Originally designated as a rare species under California law in 1980, the Shasta crayfish was listed as an endangered species by the State in 1988. The Shasta crayfish was federally listed as an endangered species on September 30, 1988 (U.S. Fish and Wildlife Service 1988). No critical habitat has been designated for this species.

The limited distribution and abundance of Shasta crayfish, coupled with an apparent decline in the species, led to its endangered status. Its distribution is limited to the midsections of the Pit River drainage, primarily the Fall River and Hat Creek subdrainages (Figure 1). The greatest densities of Shasta crayfish are found in the pristine headwater springs of the Fall River. A few of these springs support locally abundant isolated populations. Other areas, which have generally been considered marginal habitat, support a sparsely-distributed, low abundance of crayfish. Overall, Shasta crayfish have a low abundance and fragmented distribution with migration and genetic exchange between populations limited by hydroelectric development and loss of habitat. No single event is responsible for its decline, but numerous natural and human disturbances over time have collectively resulted in the reduced abundance and fragmented distribution of the Shasta crayfish.

Of the three species of crayfish endemic to California, only the Shasta crayfish (formerly called the placid crayfish, but renamed because it is found only in Shasta County) remains. The sooty crayfish (*Pacifastacus nigrescens*), was the species most closely related to Shasta crayfish. It has not been collected since the mid-1800's. Once a common inhabitant of creeks in the vicinity of San Francisco, the sooty crayfish is now considered extinct due to overharvesting, urbanization,

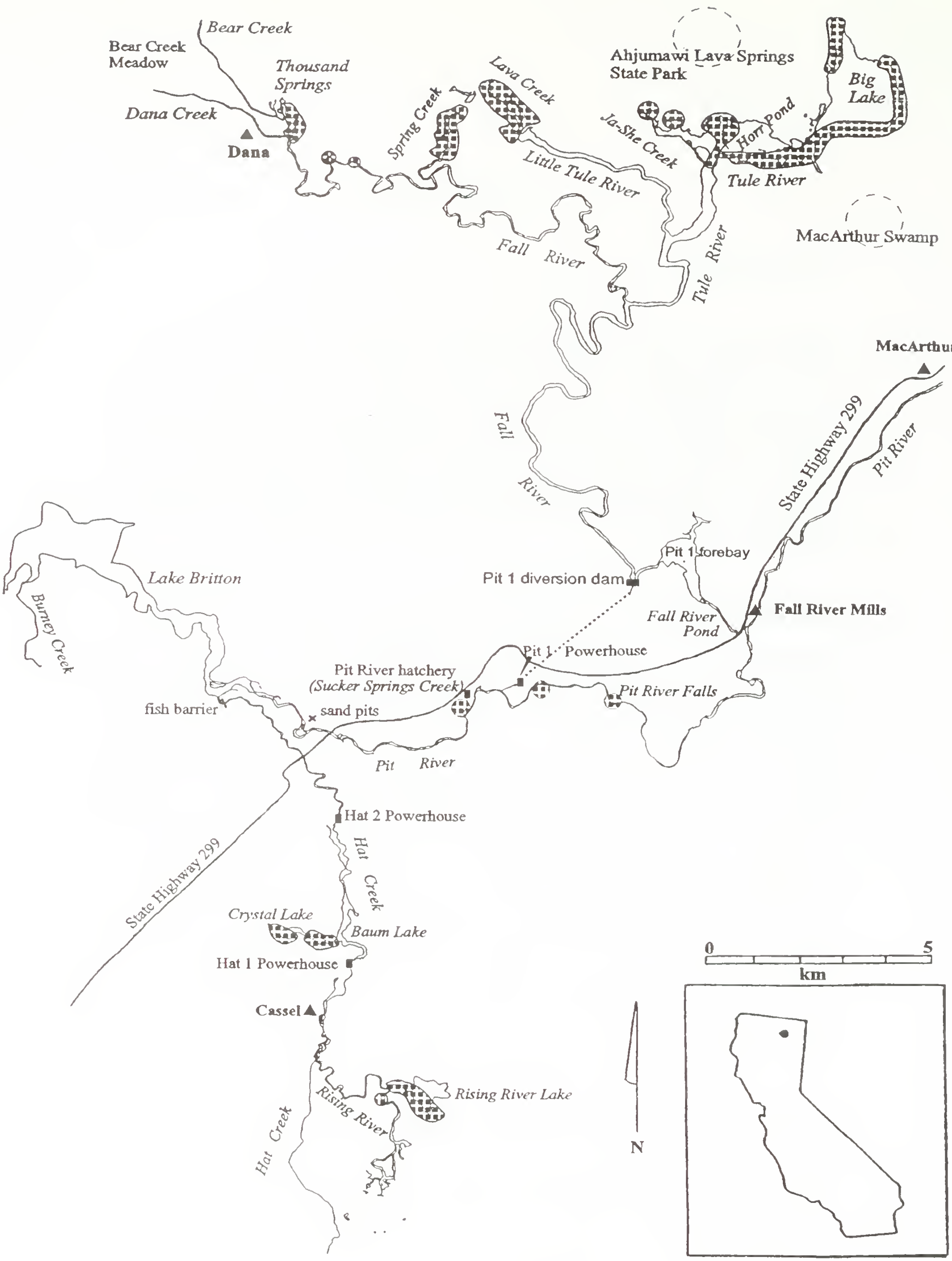


Figure 1. Distribution of all known locations of Shasta crayfish in Shasta County, California ( )

and the introduction of the nonnative *Pacifastacus leniusculus leniusculus*, the signal crayfish, to the San Francisco Bay area in the late 1800's (Reigel 1959, Hobbs 1974, 1989, Bouchard 1977a). Subspecies of *Pacifastacus leniusculus* have been widely introduced throughout the state and world, including the Klamath River drainage in northwestern California where one subspecies (*Pacifastacus leniusculus klamathensis)* is native. Because of overlapping ranges and interbreeding, the different subspecies of *Pacifastacus leniusculus* are generally no longer recognizable (Hobbs 1972) because the characteristics once useful in distinguishing the subspecies are now often found on the same individual.

Within the last two decades, the signal crayfish was also introduced into the native drainage of the Shasta crayfish in northeastern California. Many events or disturbances in the last century have changed the habitat so that it is more suitable to a generalist such as the signal crayfish, a species capable of adapting to a broad range of conditions, than to a specialist such as the Shasta crayfish, a species that tolerates only a narrow range of conditions. The rapid expansion of signal crayfish and the apparent decline of Shasta crayfish in this area suggests that signal crayfish may replace Shasta crayfish as the signal crayfish once probably replaced the sooty crayfish in the San Francisco Bay area.

B. Taxonomy

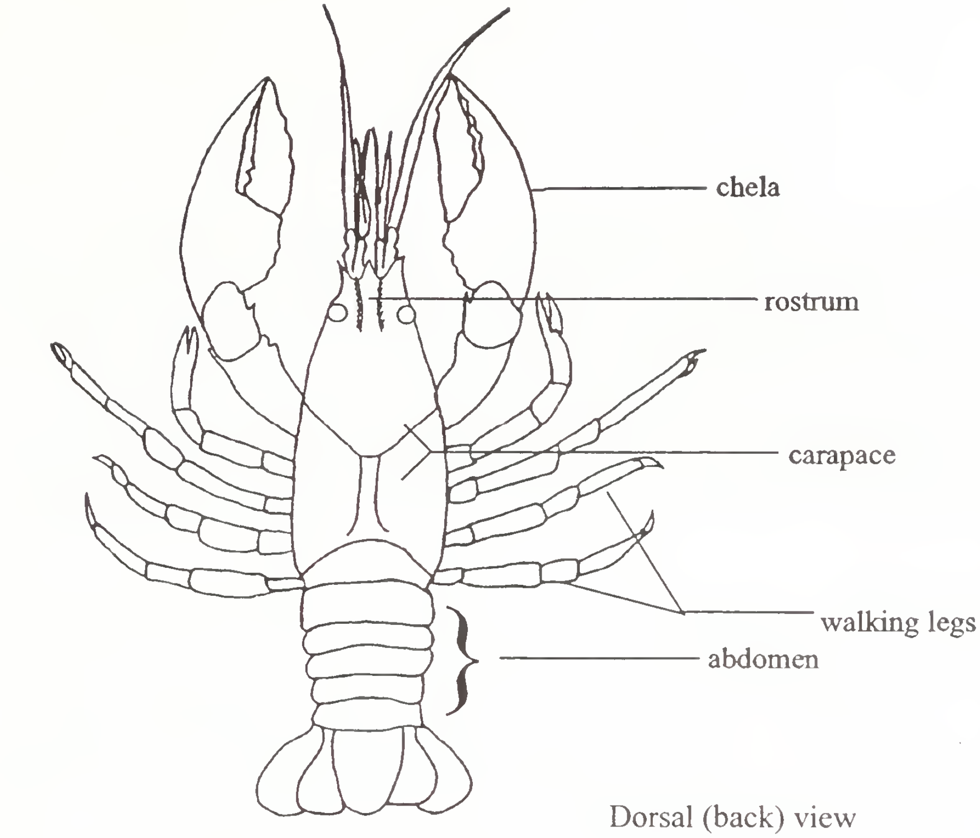
Shasta crayfish were first collected by Rutter and Chamberlain in 1898 in the Fall River at Fall River Mills and Hat Creek near Cassel during a United States Fish Commission study (Rutter 1903, 1908). Fall River Mills is the type locality, the place where the specimen used to describe the species' distinguishing characteristics was collected. Faxon (1914), using Rutter's 1898 collections, described Shasta crayfish as *Astacus nigrescens fortis*, because he believed it was a subspecies of the San Francisco Bay area sooty crayfish. In 1950, Bott

separated the North American members of this genus into the genus *Pacifastacus* and retained the generic name *Astacus* for some of the Eurasian members of the genus (Eng and Daniels 1982). Hobbs assigned full species status to the Shasta crayfish, *Pacifastacus fortis*, in 1972. The Shasta crayfish remained in the family Astacidae when Hobbs created the family name Cambaridae in 1972 for a group of species that share a distinguishing characteristic and are all native to areas east of the Continental Divide. Bouchard (1978) placed Shasta crayfish in the subgenus *Hobbsastacus* because the rostrum, the area between the eyes in the most anterior portion of the head/carapace (the shell covering the head and midregion over the walking legs) has multiple pairs of marginal spines (Figure 2) that strongly resemble four other members of the genus *Pacifastacus* that are also placed in the subgenus *Hobbsastacus*: *P. chenoderma* (fossil), *P. connectens*, *P. gambelii*, and *P. nigrescens.*

C. Species Description

Shasta crayfish are medium-sized; the total length of a typical adult is 27–50 millimeters (1.06–1.97 inches), as measured on the carapace. The most common coloration pattern for Shasta crayfish is a dark mocha brown on the back and a bright orange red on the underside, especially on the pincher-like claws (chelae). An occasional individual is encountered that has a blue-green to bright blue dorsal (back) surface and a light salmon ventral (abdominal) surface.

Shasta crayfish have a toothed (denticulate) margin on the anterior portion of the head between the eyes (rostrum) (Figure 2). In signal crayfish, the rostrum has three parts or protrusions (tripartite rostrum). The absence of patches of bristles (setal patches) on their claws separate Shasta crayfish from *Pacifastacus connectens* (native to Idaho, northern Nevada, northern Utah, and eastern Oregon) and *Pacifastacus gambelii* (a northern Rocky Mountains/Great Basin species). Shasta crayfish have shorter and thicker claws than the sooty crayfish, whose claws are long and narrow (Hobbs 1989).



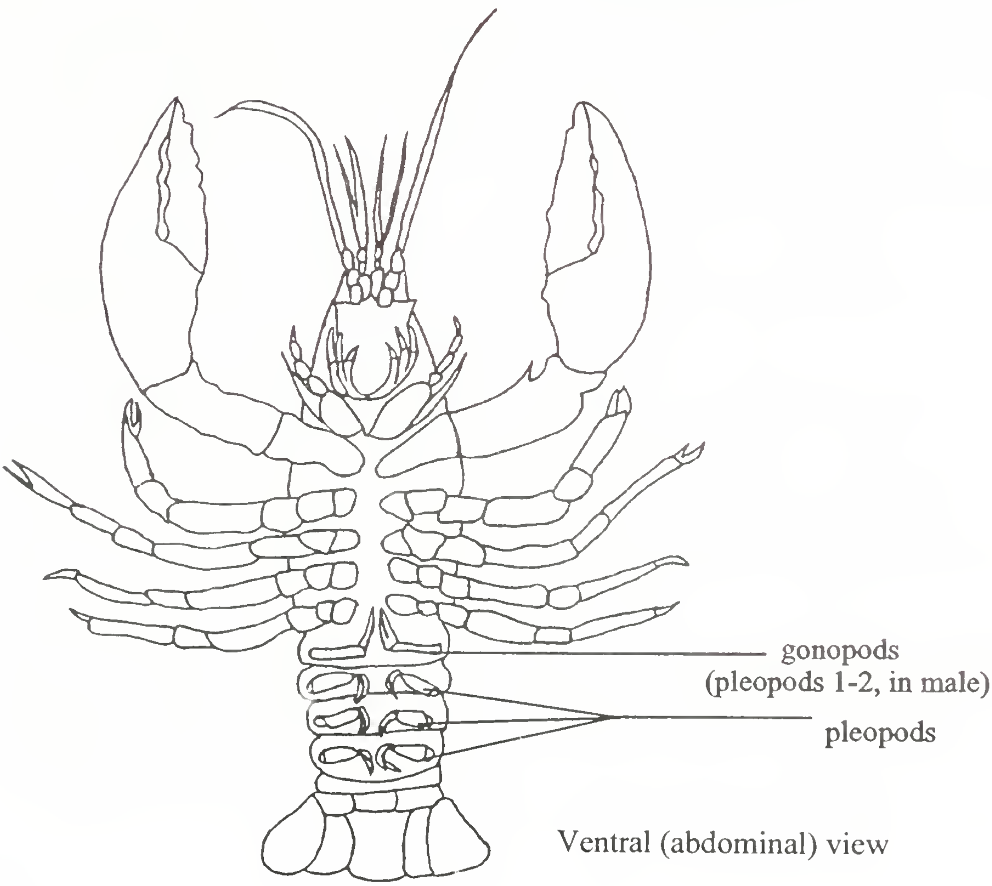


Figure 2. Anatomy of a crayfish.

Shasta crayfish are sexually dimorphic (males and females are physically different). The first two pairs of abdominal appendages (pleopods or swimmerets) are hardened and modified in males for sperm transfer to females. In addition, adult males have narrower abdomens and larger claws than females. Adult females have broader abdomens with lateral extensions of the exoskeleton on the abdomen (pleura). In addition, the first pair of abdominal appendages is absent in females.

D. Life History and Ecology

Like most crayfish, Shasta crayfish are nocturnally active and remain hidden during the day. In general, Shasta crayfish come out from hiding only after dark to browse on the periphyton (i.e., the community of plants, animals, and associated detritus, or debris) that adhere to and form a surface coating on the abundant lava rocks. Shasta crayfish that are found in the open during daylight have generally been disturbed from their refuge or may to be ill (M. Ellis, personal observation [pers. observ.]).

Shasta crayfish are long-lived and slow-growing. Although age-class boundaries are often not very distinct, especially in older reproductive crayfish, the relative age of individual Shasta crayfish can be estimated from graphs based on data showing the relationship between age and size (size-frequency histograms). It takes 5 years for a Shasta crayfish to reach sexual maturity at 27 millimeters (1.06 inches). The largest Shasta crayfish found to date, with a total carapace length (TCL) of 58.7 millimeters (2.31 inches), was probably 10–15 years old.

Mating occurs in October or November when the male deposits a capsule containing sperm (spermatophore) on the underside of the female near her genital opening at the base of the fifth walking legs (pereiopods). Shortly afterwards, the female lays 10–70 eggs, which she fertilizes with sperm from the spermatophores,

and then attaches to the underside of her abdomen or tail. In the spring, the eggs hatch into immature larval forms, the first instars, that are attached to the underside of her abdomen by threads to the inner egg membrane. These molt into second instars, which are miniatures of the adult, and clasp the female with their tiny claws. After a second molt, the third instars reach a total carapace length of 5–7 millimeters (0.2–0.27 inches) and gradually become free-living (Holdich and Reeve 1988).

Potential Food Resources. Little is known about the food preferences and nutritional requirements of Shasta crayfish. The failure to capture this species by using baited traps (Eng and Daniels 1982) led to the conclusion that Shasta crayfish were either carnivores (meat eaters) or browsers (grazing on aquatic vegetation) rather than omnivorous scavengers (feeding on dead or decaying plants and animals) like signal crayfish, which are readily lured to baited traps. These differences in feeding are reflected in differences in the mouthpart structures (Bouchard 1977b). Shasta crayfish have been observed feeding on a small blackish-green snail (*Fluminicola*) (Light 1990, unpublished [unpubl.] field notes), eating a strand of dead aquatic vegetation that was probably a filamentous green algae (*Rhizoclonium*) (Clarke 1990, unpubl. field notes), and feeding on organic debris.

Shasta crayfish have been observed on rocks with their mouthparts moving, suggesting they are eating organisms attached to rocks (periphyton) and possibly snails; however, crayfish can also move their mouthparts as a sensory behavior when they are not feeding. Shasta crayfish have been observed moving their first walking legs (pereiopods) to their mouth or moving their claws (chelae) to suggest feeding; although the crayfish were apparently grazing, no specific food items could be identified (Ellis, pers. observ.; Erman *et al.* 1993).

Other observations have been made under artificial or experimental settings that would affect crayfish behavior. Shasta crayfish kept in aquaria have fed on both freshwater limpets (*Lanx* spp.) and tubifex worms (Eng and Daniels (1982). During one series of experiments, Shasta crayfish were fed crayfish chow, meal worms, and brine shrimp (Mojica *et al.* 1993). Although there was almost complete mortality of the crayfish, it was assumed that high temperatures were the primary cause of death. It was not known whether the diet fed to these Shasta crayfish met the species' nutritional requirements. One Shasta crayfish was observed eating a dead juvenile rainbow trout during an enclosure experiment in Crystal Lake during the summer of 1993 (Ellis, pers. observ.). Shasta crayfish in the Pit 1 Laboratory have been observed eating numerous snails, particularly *Fluminicola* spp. and to a lessor extent *Juga* spp. (Ellis, pers. observ.)

It is likely that Shasta crayfish consume other invertebrates as well. Other potential food resources include trout, sucker, and sculpin eggs, which are seasonally abundant. Although some of the items Shasta crayfish will consume are known, nothing is known about their actual nutritional requirements. Some understanding of the nutritional requirements of Shasta crayfish is necessary before undertaking any further attempts at long-term captive breeding programs.

Potential Predators. Many native and introduced fish species in the midsections of the Pit River drainage prey on crayfish (Table 1). Some species are occasional benthic feeders that would probably eat small crayfish, particularly young of the year (YOY), when encountered. Other potential predators include bullfrogs, turtles, garter snakes, mammals, and a variety of birds. Bullfrogs, which are not native west of the Rockies (Stebbins 1985), were introduced and are now common in Crystal Lake and Big Lake. Bullfrogs prey on crayfish (Tack 1941, Penn 1950). Although many turtles eat crayfish (Tack 1941, Lagler and Lagler 1944), no references to western pond turtle predation on crayfish were found. Garter snakes to eat crayfish on occasion. Two of the three native aquatic

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

	Common Name	Scientific Name	Crayfish Predator	Comments
Fish[1]	Rainbow trout	*Oncorhynchus mykiss*	Yes	Spring areas; eggs are a potential food resource for Shasta crayfish
(Native)	Sacramento sucker	*Catostomus occidentalis*	Possible	Spring areas; eggs are a potential food resource for Shasta crayfish; probably eat Shasta crayfish young-of-the-year (YOY)
	Pit-Klamath brook lamprey	*Lampetra lethophaga*		Spring areas; eggs are a potential food resource for Shasta crayfish
	Rough sculpin	*Cottus asperrimus*	Possible	Spring areas; found throughout Fall River drainage; low numbers in Pit River and lower Hat Creek (downstream from Rising River subdrainage); eggs are a potential food resource for Shasta crayfish; probably eat Shasta crayfish YOY; State listed as threatened and Federal species of concern
	Bigeye marbled sculpin	*Cottus klamathensis macrops*	Possible	Spring areas; found throughout Fall River drainage; low numbers in Pit River and lower Hat Creek (downstream from Rising River subdrainage); eggs are a potential food resource for Shasta crayfish; probably eat Shasta crayfish YOY; State species of concern
	Sacramento squawfish	*Ptychocheilus grandis*	Yes	Lakes and rivers; spawn in spring areas

[1] Taub 1972, Rickett 1974, J. Cook, pers. comm. 1995, Eng unpubl. data, CDFG unpubl. records

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

	Common Name	Scientific Name	Crayfish Predator	Comments
	Pit sculpin	*Cottus pitensis*	Possible	Only sculpin in Rising River subdrainage and upper Hat Creek; also native to lower Hat Creek, Sucker Springs Creek, and mainstem Pit River; not found in Fall River drainage, or Crystal Lake; eggs are a potential food resource for Shasta crayfish; probably eat Shasta crayfish YOY
	Hardhead	*Mylopharadon conocephalus*	Possible	Native to midsections of Pit River drainage, but not generally found with Shasta crayfish; probably eat Shasta crayfish YOY
	Tui chub	*Gila bicolor*	Possible	Native to midsections of Pit River drainage, but not generally found with Shasta crayfish; probably eat Shasta crayfish YOY
	Tule perch	*Hysterocarpus traski*		Native to midsections of Pit River drainage, but not generally found with Shasta crayfish
Fish[1]	Brown trout	*Salmo trutta*	Yes	Spring areas, especially in fall spawning season
(Introduced)	Brown bullhead	*Ameiurus nebulosus*	Yes	Crystal Lake
	Largemouth bass	*Micropterus salmoides*	Yes	Successful in using Shasta crayfish habitat, including some spring areas
	Green sunfish	*Lepomis cyanellus*	Yes	Not generally found with Shasta crayfish

[1] Taub 1972, Rickett 1974, J. Cook, pers. comm. 1995, Eng unpubl. data, CDFG unpubl. records

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

	Common Name	Scientific Name	Crayfish Predator	Comments
	Bluegill	*Lepomis macrochirus*		
	Black crappie	*Pomoxis nigromaculatus*	Yes	
	Smallmouth bass	*Micropterus dolomieu*	Yes	
	Bluegill	*Lepomis macrochirus*		
	Brook trout	*Salvelinus fontinalis*		Not generally found with Shasta crayfish
	Channel catfish	*Ictalurus punctatus*	Yes	Not generally found with Shasta crayfish
	White catfish	*Ameiurus catus*		Not generally found with Shasta crayfish
	Common carp	*Cyprinus carpio*	Possible	Not generally found with Shasta crayfish
	Golden shiner	*Notemigonus crysoleucas*		Not generally found with Shasta crayfish
	Black bullhead	*Ameiurus melas*	Yes	Not generally found with Shasta crayfish
	Mosquito fish	*Gambusia affinis*		Not generally found with Shasta crayfish
Benthic Invertebrates				
Crayfish	Signal crayfish	*Pacifastacus leniusculus*		Nonnative species; interferes with and replaces Shasta crayfish; potential to transmit pathogens and parasites to Shasta crayfish
	Fantail crayfish	*Orconectes virilis*		Nonnative; potential competitor with Shasta crayfish; potential to transmit pathogens and parasites to Shasta crayfish

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

	Common Name	Scientific Name	Crayfish Predator	Comments
Mussels[2]	California floater	*Anodonta californiensis*		Federal species of concern
	Montane peaclam	*Pisidium ultramontanum*		Federal species of concern
	Western ridgemussel	*Gonidea angulata*		
	Western pearshell	*Margaritifera falcata*		
Snails		*Juga acutifilosa*		Abundant and commonly found in spring areas; generally found on lava substrate; Shasta crayfish fed on snails in this genus in captivity
		Fluminicola seminalis		Abundant and commonly found in spring areas; found on green algae (*Rhizoclonium hookeri*, but not *Spirogyra* spp.); Shasta crayfish observed feeding on snail thought to be in this genus[3] and fed on snails in this genus in captivity
		Lanx patelloides		
		Physella gyrina		Associated with fine sediment in larger lakes and rivers
		Helisoma newberryi		Associated with fine sediment in larger lakes and rivers
		Vorticifex effusa		

[2] Signal crayfish were observed eating mussels (M. Ellis, pers. observ.).

[3] Light 1990, unpubl. field notes

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

	Common Name	Scientific Name	Crayfish Predator	Comments
Birds[4]	Great blue heron	*Ardea herodias*	Yes	
	Belted kingfisher	*Ceryle alcyon*	Yes	
	Green-backed heron	*Butorides striatus*	Yes	
	Black-crowned night heron	*Nycticorax nycticorax*	Yes	
	American bittern	*Botaurus lentiginosus*	Yes	
	Bufflehead	*Bucephala albeola*	Possible	
	Common goldeneye	*Bucephala clangula*	Possible	
	Ring-necked duck	*Aythya collaris*	Possible	
	Western grebe	*Aechmophorus occidentalis*	Possible	
	Pied-billed grebe	*Podilymbus podiceps*	Possible	
	Double-crested cormorant	*Phalacrocorax auritus*	Possible	
	Sora	*Porzana carolina*	Possible	
	Virginia rail	*Rallus limicola*	Possible	
	Spotted sandpiper	*Actitis macularia*	Possible	

[4] Tack 1941, Lagler and Lagler 1944

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

	Common Name	Scientific Name	Crayfish Predator	Comments
Mammals[5]	River otter	*Lutra canadensis*	Yes	
	Mink	*Mustela vison*	Yes	
	Beaver	*Castor canadensis*	No	Herbivores and not likely to impact crayfish
	Muskrat	*Ondatra zibethica*	Yes	Destabilize banks and increase sediment
	Raccoon	*Procyon lotor*	Yes	
Amphibians[6]	Bullfrog	*Rana catesbeiana*	Yes	Introduced and now common in Crystal Lake and Big Lake
Reptiles[7]	Western pond turtle	*Clemmys marmorata*	Possible	
	Garter snake	*Thamnophis* spp.	Yes	
Aquatic Vegetation[8]	Green algae	*Rhizoclonium* spp.		Colder spring areas; dominant vegetation in headwater spring areas where most Shasta crayfish populations are found; Shasta crayfish observed feeding strand of dead aquatic vegetation thought to be in this genus.[9]

[5] Errington 1941, Burt and Grossenheider 1976, MacDonald 1985, Hanson *et al.* 1989, M. Ellis, pers. observ.
[6] Tack 1941, Penn 1950, Stebbins 1985
[7] Tack 1941, Lagler and Lagler 1944
[8] Ellis and Hesseldenz 1993
[9] Clarke, unpubl. field notes

Table 1. Animal and plant species associated with in the Pit River and its subdrainages (Figures 1 and 3).

Common Name	Scientific Name	Crayfish Predator	Comments
Buttercup	*Ranunculus* spp.		Colder spring areas; patchy and covers small amounts of habitat
Water-milfoil	*Myriophyllum* spp.		Colder spring areas; patchy and covers small amounts of habitat
Green algae	*Spirogyra* spp.		Covers large areas in Little Tule, Tule, and lower Fall Rivers; usually found in eutrophic waters; not generally found with Shasta crayfish
Waterweed	*Elodea* spp.		River species; large amounts with *Zannichellia* spp. in Fall, Tule, and Little Tule Rivers; found near shores of Pit 1 Forebay, Fall River Pond, Big Lake; some below Pit 1 Powerhouse
Horned-pondweed	*Zannichellia* spp.		River species; large amounts with *Elodea* spp. in Fall, Tule, and Little Tule Rivers and found near shores of Pit 1 Forebay, Fall River Pond, Big Lake; some below Pit 1 Powerhouse
Hornwort	*Ceratophyllum* spp.		Associated with streambanks in Big Eddy pool above the Pit River Canyon.

mammals, river otters and mink, prey on crayfish. Observations of a pair of river otters feeding on crayfish in the Pit River indicate that they are extremely effective and efficient crayfish predators, and most of the river otter scat found in the area is composed solely of pieces of crayfish shell (Ellis, pers. observ.). Muskrats were introduced into the drainage in the late 1920's, and racoons also eat crayfish. Beavers are herbivorous and unlikely to impact crayfish.

One of the largest great blue heron rookeries in California is located in Ahjumawi Lava Springs State Park (Figure 1) along Ja-She Creek. A smaller great blue heron rookery is found on an island in the Pit River downstream of the State Highway 299 bridge. The impact of avian predators on Shasta crayfish is unknown.

E. Habitat and Ecosystem

Physical Environment

Geologic Background. The past and present distribution of the Shasta crayfish is integrally tied to the geologic history of the Modoc Plateau, an immense lava field covering most of northeastern California. Because volcanic rock is porous, most rainfall percolates through the lava into the groundwater. Surface water is minimal, so rainfall from over 80 kilometers (50 miles) away and snowmelt from Mt. Shasta, Lassen Peak, and other lesser peaks feed the groundwater that comes to the surface at contact springs (formed where permeable lava flows overlie less-permeable material such as lakebed sediment) in the midsections of the Pit River drainage. The midsections of the Pit River drainage lies along the western margin of the Modoc Plateau geomorphic province.

Evidence from a recent study indicates that Lassen volcanic highlands is the recharge area (source of water) for springs where Shasta crayfish are found in the Hat Creek Basin (Rose *et al.* 1996). Precipitation on the Lassen volcanic highlands percolates through the lava into a large central aquifer system underlying Hat Creek valley, which supplies water to Rising River and Crystal Lake springs. The hydrologic features of the Fall River spring system are very similar to those of the Hat Creek basin springs. Preliminary data indicates that the Medicine Lake Highlands is the source of water for the Fall River springs (Rose *et al.* 1996). The Fall River and Rising River subdrainages, and to a lesser extent Hat Creek and the midsections of the Pit River, are characterized by extensive cold water springs (9–12 degrees Celsius; 48.2–53.6 degrees Fahrenheit). The volcanic origin of the area is also responsible for the dominant feature of Shasta crayfish habitat: lava cobble and boulders.

The second major geologic feature that determines the location of many of the springs in the area is the extensive deposits originating from large lakes that existed prehistorically. The Fall River and Hat Creek basins were part of a large lake or series of lakes that connected the Klamath Basin, in Oregon, and northern California (Russell 1885, Meinzer 1922, Hanna and Gester 1963). These prehistoric lakes also feature prominently in the zoogeography (animal distribution) of the region (Taylor and Smith 1981, Taylor 1985).

Drainage Description (Figure 1). The Pit River, which drains most of northeastern California, meanders through marshy pasture along the broad, low-gradient valley floors of its upper drainage in Lassen and Modoc Counties. Although the tributary streams of the upper Pit River are precipitous, cold and clear, the upper Pit River is often multichanneled, slow flowing, warm, and turbid. The upper river once flowed through indefinite channels creating extensive marshlands through the valleys in its upper drainage (Moyle and Daniels 1982). Most of these marshlands, however, have now been drained, with 20–25 percent

of the water diverted for irrigation and the river and lowland portions of the tributaries channelized (Moyle and Daniels 1982).

The character of the Pit River changes below the mouth of Fall River, one of its largest tributaries. The Fall River is renown for its size, flow, and clarity, which result from countless springs throughout its upper sections (Figure 3). Historically, the Fall River flowed over a series of falls into the Pit River at Fall River Mills. Now, virtually all of the Fall River's flow is diverted through the Pit 1 Powerhouse and enters the Pit River 10 kilometers (6.2 miles) below the point where the two rivers originally merged. At present, there are no regular releases of water into the 1.1 kilometers (0.68 mile) section of the Fall River channel upstream from the Pit River. The only water in this section downstream from the Fall River Weir (concrete dam with gates) is from seepage, except during occasional floods and spills. Below the historic mouth of Fall River, the Pit River is fed by numerous small springs as it flows through 7 kilometers (4.3 miles) of steep-walled, moderate-gradient canyon and over the Pit River Falls, which are approximately 12 meters (40 feet) high. After the springs in the Pit River canyon (Figure 3) and the Fall River water (via the Pit 1 Powerhouse) contribute their cooling flows, the Pit River becomes a rapidly flowing, high volume, moderately cold-water river. Water enters the Pit River downstream of the Pit 1 Powerhouse from several springs, including three major spring-fed tributaries: Sucker Springs Creek, Hat Creek, and Burney Creek (Figure 1). Hat Creek is the largest of these tributaries; the majority of its water comes from the Rising River subdrainage, whose springs are sustained by snowmelt from the Lassen Volcanic National Park area (Rose *et al.* 1996).

Aquatic Environment

Shasta crayfish are generally found in the cold, clear, spring-fed headwaters of the midsections of the Pit River drainage, particularly in the headwaters of the Fall

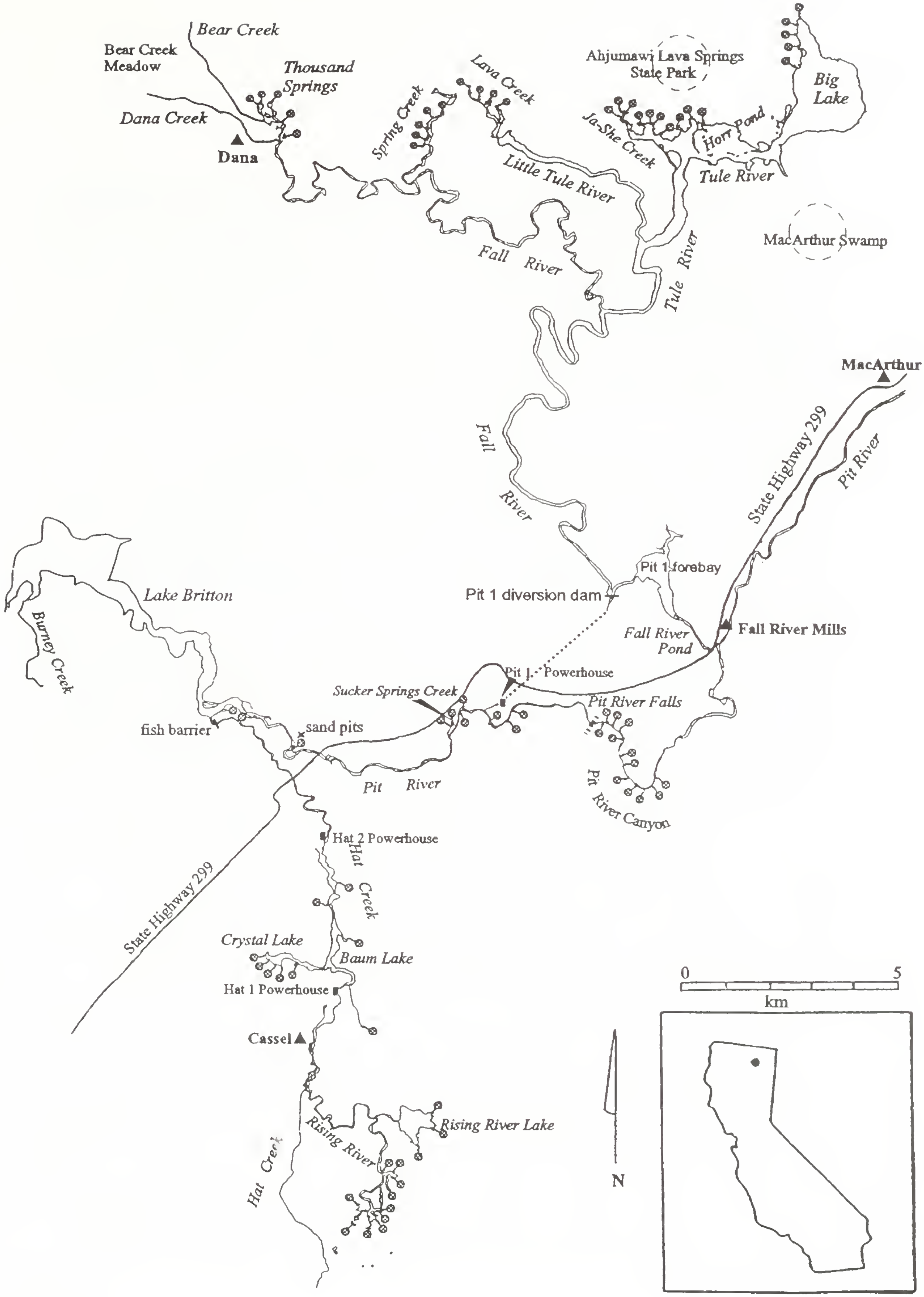


Figure 3. Distribution of springs ( ) in the midreaches of the Pit River drainage

River subdrainage. Shasta crayfish are generally found in habitat characterized by clean volcanic cobbles and boulders on gravel or sand. In general, Shasta crayfish habitat is defined by the availability of cover, or refugia (protected places) provided by clean lava cobbles and boulders on gravel or sand. Although potential food resources, temperature, and water chemistry constituents (e.g., dissolved oxygen, calcium, pH) may also limit the distribution of Shasta crayfish, the range of these conditions where Shasta crayfish are found is considerable.

Substrate. During the Pit 1 rare species study (Ellis and Hesseldenz 1993), substrate was identified as silt, sand, Bear Creek gravel, lava gravel, lava cobbles, lava boulders, lava bedrock, diatomaceous earth/clay (earth composed of the shells of diatoms, a type of algae), or earthen clumps. Substrate in the upper Fall River consists predominantly of fine sediment (sand and silt) with patches of lava cobbles and gravel. The upstream portion of this section has received deposits of Bear Creek gravel during the high flows of some winters. Sedimentary materials from Bear Creek have created extensive beds of gravel that cover 94 percent of the river channel from Bear Creek (Figure 1) to Read's bridge. Below the mouth of Bear Creek, the gravel covers the west side of the river channel for 0.8 kilometer (2,600 feet) downstream to the Navigation Limit (the southern boundary of Section 19, Township 38 North, Range 4 East). This shallow, 0.1–0.75 meter (4–30 inches) deep, segment of river constitutes the only moderate-gradient section of the entire Fall River. At the Navigation Limit the river bends to the west, and Bear Creek gravel extends completely across the river, burying most lava substrate.

The substrate in the lakes and reservoirs consists primarily of fine organic sediment with little to no natural lava substrate. Lava, however, was imported to Big Lake during levee maintenance in the 1930's.

Tule River, Little Tule River, and lower Fall River below the mouth of Tule River are variable-temperature, slow-moving, low-gradient rivers that are characterized

by seasonal variations in temperature (5–23 degrees Celsius) and turbidity, with warm eutrophic water (nutrient-rich and low oxygen) in the summer (Ellis and Hesseldenz 1993). These rivers are moderately wide with an average depth of 2.5–3.0 meters (8–10 feet). The substrate in these rivers is predominantly silt and fine organic matter. Although there is little to no natural lava substrate, some lava was imported into these rivers for levee maintenance and bridge construction.

The Pit River is a variable-temperature (5–23 degrees Celsius), moderate-gradient (1.6 percent slope) river from its entrance into the canyon at Big Eddy, 3.6 kilometers (2.2 miles) below the mouth of Fall River, to Lake Britton, 14.2 kilometers (8.8 miles) downstream. The substrate in the Pit River consists predominantly of large boulders.

Fish. The fish community in the midsections of the Pit River drainage comprises both native and nonnative species. The fish community in the spring areas is composed of predominately native species (Table 1). Chinook salmon (*Oncorhynchus tshawytscha*) were found in the Pit River prior to the completion of downstream hydroelectric dams. Spring runs of chinook ascended the Pit River into Hat Creek and some even passed the Pit River Falls to ascend the Fall River to its source near Dana (Rutter 1903).

Benthic Invertebrates. The midsections of the Pit River drainage support a diverse community of benthic (living on the bottom) invertebrates (Table 1), including the Shasta crayfish and two introduced species of crayfish. There is a diverse freshwater molluscan community. Several species of snails are associated with the spring-fed headwater areas. Extensive middens, or waste piles, of freshwater mussel shells are found throughout the drainage, especially along Big Lake and Tule River. These middens reflect both muskrat predation and the long-time history of mussel use by the Achumawi and Atsugewi tribes.

Aquatic Vegetation. Aquatic vegetation (Table 1) in the spring areas of the Pit River drainage covers from 0–35 percent of the bottom (benthic coverage) (Ellis and Hesseldenz 1993). Aquatic vegetation covers much of the bottom in the man-made reservoirs such as Pit 1 Forebay and Fall River Pond, ranging between 30–95 percent, and in the rivers coverage ranges from 15–25 percent (Ellis and Hesseldenz 1993). The vegetation in the upper Fall River is a mix of spring-type vegetation (i.e., *Myriophyllum* and *Rhizoclonium*) and river-type vegetation (i.e., *Elodea* and *Zannichellia*). Vegetation covers about 30 percent of the upper Fall River (Ellis and Hesseldenz 1993). In 1992, small patches of spring-type vegetation occurred in the upper Fall River above the PG&E Pipeline crossing, while extensive beds of *Elodea* and *Zannichellia* dominated the river channel downstream (Ellis and Hesseldenz 1993). Significant amounts of aquatic vegetation do not occur in the Pit River canyon upstream of the Pit 1 Powerhouse. Above the canyon in Big Eddy pool, there are patches of *Ceratophyllum* associated with the streambanks. There are a few extensive beds of *Elodea* and *Zannichellia* in the Pit River downstream of the Pit 1 Powerhouse.

F. Distribution and Population Status

Historic Distribution

Although it is impossible to determine the exact historic range and distribution of the Shasta crayfish, information on the ancestral range may be derived from the study of the distribution (zoogeography) and history of crayfish collections in this region (Figure 4). The unique volcanic and spring environment of this area (Figure 3) supports a number of rare and endemic species, including sculpin and molluscs found only within the Fall River system and a few nearby springs in the Hat Creek and Pit River drainages (Moyle and Daniels 1982, Taylor 1981). This distinct zoogeographical region is defined by a constant supply of cold, clear, spring water and lava substrate that does not occur in the Pit River above the mouth of Fall River and is less common below the mouth of Burney Creek.

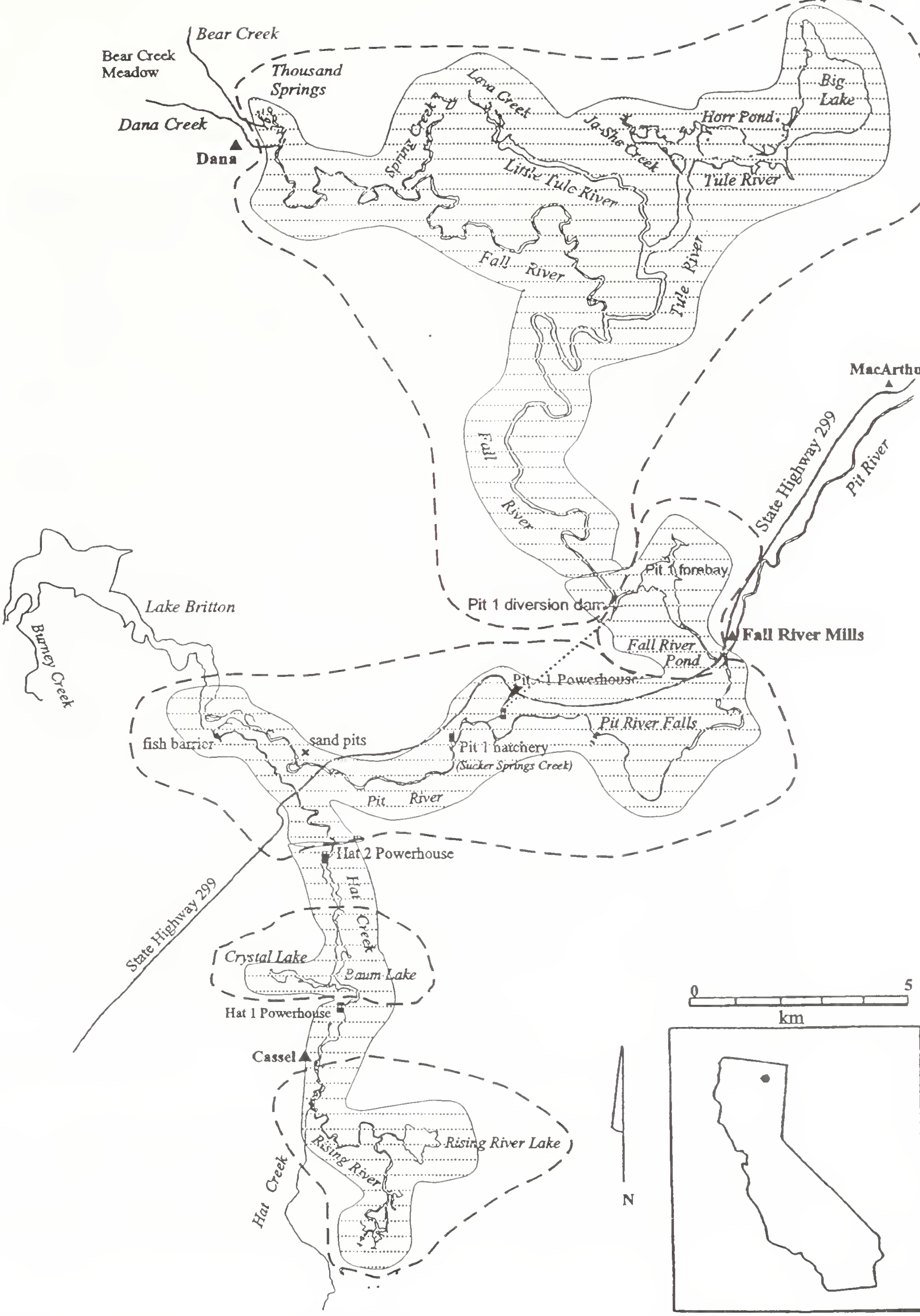


Figure 4. The historic range of Shasta crayfish with five regions (⬭) isolated by early twentieth century hydroelectric development (– –).

Shasta crayfish are considered a relict species, a species surviving from a much earlier era, whose ancestral range was reduced by geologic and related climatic changes (Bouchard 1978). Historic and zoogeographical evidence, however, indicates that the historic range (i.e., the limits of the geographic distribution) of the Shasta crayfish has remained relatively unchanged during the period of recorded history (Ellis, submitted). All known collections of Shasta crayfish are within the limits of their current range.

Although the limits of its range appears to be relatively unchanged in historical times, the distribution of Shasta crayfish within that range is probably more fragmented than it was historically. Shasta crayfish, however, were probably never continuously distributed throughout their range. The strong correlation between Shasta crayfish and lava substrate, and the discontinuous distribution of lava substrate in the drainage indicate that the distribution of Shasta crayfish was most likely always patchy. Large areas of lava substrate, however, have become unavailable to Shasta crayfish during this century as a result of habitat alterations (e.g., excavations, impoundments, water diversions, and sedimentation) and the colonization of lava substrate by introduced crayfish.

Many of the disjunct populations of Shasta crayfish are isolated not only by distance, but by barriers both natural and resulting from human activities, such as hydroelectric development. Given that Shasta crayfish once occurred in the Fall River at Fall River Mills and probably occurred in the mainstem Hat Creek near Cassel (Faxon 1914), it is plausible to conclude that Shasta crayfish occurred at other sites in between present population locations.

Although Shasta crayfish are not known to move great distances from their habitat, they have dispersed into and colonized new areas when habitat was created by the addition of lava substrate, such as the levees in the upper Tule River subdrainage (upper Tule River refers to the section of river that widens out

around Horr pond and continues up to Big Lake). In some cases, Shasta crayfish may have had to move through areas without lava substrate to reach new habitat. Even though Shasta crayfish probably did not occupy non-lava substrate areas, they may have dispersed through these areas. Such dispersal would play a key role in gene flow (i.e., the exchange of genetic material between populations through interbreeding) and the maximum use of islands of lava substrate. Periodic dispersal of a few individuals from another location, even if restricted to downstream migration, could result in adequate gene flow to maintain the genetic variability of the species.

Additional evidence of the historic distribution of Shasta crayfish has been derived from the historical food habits of two major tribes of Pit River Indians, the Achumawi (Fall River and south side of the Pit River) and Atsugewi (Hat Creek), who used crayfish as a food supply (Voegelin 1942). Stone fish traps in the shallow spring areas of the Fall and Pit Rivers built to catch Sacramento suckers (*Catostomus occidentalis*) during spawning (Evans 1987, Dreyer and Johnson 1988) had the greatest densities of Shasta crayfish in the Fall River headwaters, because the lava boulder and cobble walls and lava cobble and gravel substrate of the traps provide excellent habitat for Shasta crayfish. Although there is little information pertaining to the use of crayfish by early Americans, the available data give no indication of a broader historic range for the Shasta crayfish. No crayfish were reported in the native environment along the upper Pit River (Voegelin 1942).

Current Distribution

Since 1921–1922, the Fall River has been separated from the Pit River by the operations of the Pit 1 Hydroelectric Project, the Pit River was separated from the Hat Creek drainage by construction of the Hat 2 Powerhouse and associated structures, and the Hat 1 Powerhouse construction separated Crystal Lake from

Rising River (Figure 4). The range of the Shasta crayfish was divided into at least five populations that were geographically isolated by major physical barriers created during the hydroelectric development of the area (Figure 4): (1) the Fall River drainage above the Pit 1 Diversion dam; (2) the Fall River drainage between the Pit 1 Diversion dam and the Fall River Weir; (3) the Pit River, including Sucker Springs Creek, and lower Hat Creek downstream from Hat 2 Powerhouse; (4) Crystal and Baum Lakes; and (5) the Rising River subdrainage and Hat Creek between the point it flows into the Rising River and Cassel. In 1946, the Fall River was further divided by construction of the Pit 1 Forebay Dam. In 1968, construction of a fish barrier just upstream of the mouth of Hat Creek further divided Hat Creek and the Pit River. A dam was installed, creating a waterfall that prevented undesirable fish from moving upstream from Lake Britton into Hat Creek (Ellis, pers. comm.).

As a result of construction of these physical barriers and large stretches of unsuitable habitat in the headwaters of the Fall River, Shasta crayfish currently are isolated geographically into eight populations (Figure 5). The Fall River population, which was originally continuous, is now separated into four geographically isolated populations: (1) Upper Fall River, (2) Spring Creek, (3) Lava Creek, and (4) upper Tule River, including Ja-She Creek, upper Tule River, and Big Lake. The (5) Fall River, Fall River Mills population is considered extirpated (i.e., no longer exists). The remaining populations include the (6) Pit River, (7) Hat Creek, Cassel, and (8) Rising River populations. The seven existing populations comprise several locations or subpopulations that may or may not have genetic exchange through interbreeding (Table 2).

The first comprehensive survey of Shasta crayfish was conducted by Daniels (1980, Eng and Daniels 1982). In 1990, PG&E initiated the most thorough and extensive surveys ever undertaken in the area (Ellis 1991a, 1993a, 1994a, 1995, 1996a, 1996b, Hesseldenz and Ellis 1991, Ellis and Hesseldenz 1993). Ellis

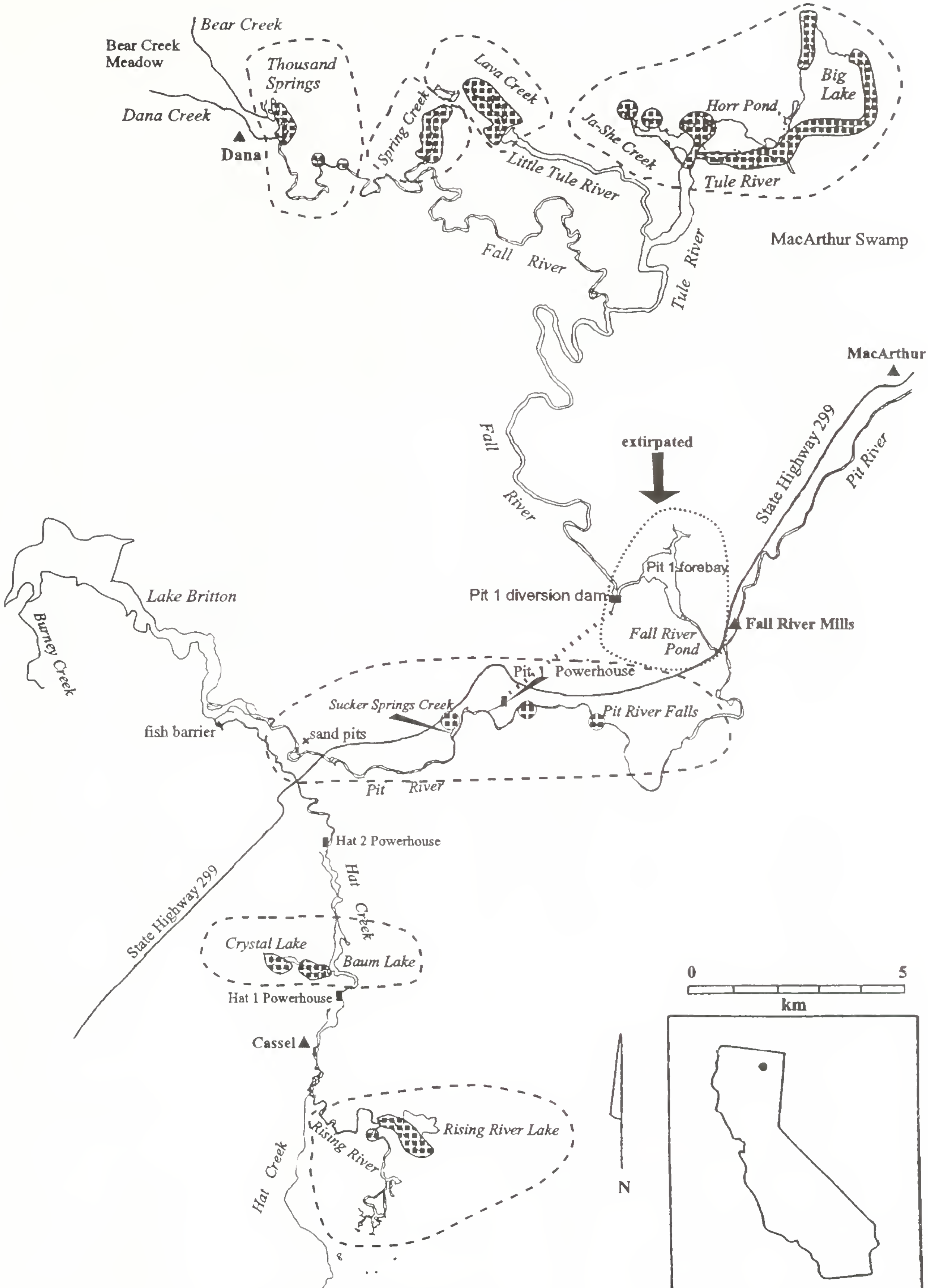


Figure 5. Location of the eight geographically-isolated populations of Shasta crayfish.

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population / Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Upper Fall River					
Thousand Springs fish trap cove	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at Navigation Limit; support landowner's management
Thousand Springs old property line	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at Navigation Limit; support landowner's management
Fall River sand springs	S	N	Private, restricted access	Signal crayfish invasion; Bear Creek gravel and sediment	Install barrier at Navigation Limit; support landowner's management; restore Bear Creek meadow
Rainbow Spring	PS	N	Private, restricted access	Signal crayfish invasion	Install barrier at Navigation Limit
Fall River above Navigation Limit	S or D	Y (S)	Private, restricted access	Bear Creek gravel and sediment; shortage of non-embedded lava substrate; further invasions and interactions with signal crayfish	Install barrier at Navigation Limit; restore Bear Creek meadow; uncover embedded lava substrate
Fall River below Navigation Limit	NS	—	Private, navigable		

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population / Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Fall River at Fletcher's bend	D	Y (S)	Private, navigable	Bear Creek gravel and sediment; shortage of non-embedded lava substrate; further invasions and interactions with signal crayfish	Restore Bear Creek meadow; add lava cobbles and boulders; install exclusion fencing along Fall River
Fall River at Lennihan's footbridge	D	Y (S)	Private, navigable	Bear Creek gravel and sediment; shortage of non-embedded lava substrate; further invasions and interactions with signal crayfish	Restore Bear Creek meadow; add lava cobbles and boulders; install exclusion fencing along Fall River
Spring Creek					
Upper coves	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Fortify barrier at Spring Creek Road crossing (culverts)
Lower fish trap cove	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion; shortage of lava cobble/boulder substrate	Fortify barrier at Spring Creek Road crossing; add lava cobbles and boulders

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Lava Creek					
Ivy Horr's northern pond	E	—	Private, restricted access; managed as wildlife refuge	Introduced largemouth bass	
Lava Creek east arm	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at outflow; support landowner's management
Lava Creek west arm	S	N	Private, restricted access; managed as wildlife refuge	Signal crayfish invasion	Install barrier at outflow; support landowner's management
Between confluence of arms and outflow	D	Y (S)	Private, restricted access; managed for fly-fishing	Further invasions and interactions with signal crayfish	Install barrier at outflow; support landowner's management; signal crayfish eradication
Lava Creek Outflow	D	Y (S)	Private, restricted access; managed for fly-fishing	Further invasions and interactions with signal crayfish	Install barrier at outflow; signal crayfish eradication

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population / Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Upper Tule River					
East shore Upper Tule River	D	Y (S)	PG&E; managed for seasonal cattle grazing	Absence of lava substrate; dredging; further invasions and interactions with signal crayfish	Substrate additions to create habitat and stabilize levees; levee bank stabilization with native grasses; eliminate dredging
South shore Upper Tule River	D	Y (S)	PG&E; managed for seasonal cattle grazing	Absence of lava substrate; dredging; further invasions and interactions with signal crayfish	Substrate additions to create habitat and stabilize levees; levee bank stabilization with native grasses; eliminate dredging
South shore Big Lake	S or D	N? (1 F in 1994)	PG&E; levees fenced; WHIP and McArthur swamp managed for wildlife and seasonal cattle grazing	Further nonnative invasions/introductions and interactions; lava substrate shortage; dredging	Install barrier near Rat Farm; substrate additions to create habitat and stabilize levees; levee bank stabilization with native grasses; eliminate dredging; signal crayfish eradication
East Big Lake	S or D	N	PG&E (lake/riverbed)	Invasion of signal crayfish	Install barrier near Rat Farm
Northeast Big Lake	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Invasion of signal crayfish	Install barrier near Rat Farm; substrate additions
North Big Lake	S	N	PG&E	Invasion of signal crayfish	Install barrier near Rat Farm

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population / Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Big Lake Springs	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Invasion of signal crayfish	Install barrier near Rat Farm
Northwest Big Lake	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Invasion of signal crayfish	Install barrier near Rat Farm; substrate additions
Northeast Upper Tule River	D	Y (S)	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Further signal crayfish invasions and interactions; fantail crayfish invasion; absence of lava substrate	Install barrier near Rat Farm; substrate additions to create habitat and stabilize levees; signal crayfish eradication
Horr Pond Levees	S	N	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Invasion of signal crayfish; absence of lava substrate	Substrate additions to create habitat
Tule Coves	S or D	Y (S)	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Further signal crayfish invasions and interactions	Install barrier; signal crayfish eradication
Crystal Springs, Cove, and Inlet	S or D	N?	PG&E (lake/riverbed); CDPR (Ahjumawi Lava Springs SP)	Further signal crayfish invasions and interactions	Install barrier
Ja-She Creek headwaters	S	N	PG&E (water rights); CDPR (Ahjumawi Lava Springs SP)	Invasion of signal crayfish	Install barrier at Ahjumawi SP Road crossing; signal crayfish eradication
Fall River, Fall River Mills					
Fall River Pond	PE	---	PG&E		

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Pit River					
Pit River Falls	S or D	Y (F)	PG&E	Interactions with fantail crayfish; signal crayfish invasion; water quality	Determine distribution, abundance, and relative abundance in mainstem
Pit River Canyon Spring	S or D	Y (S&F)	PG&E	Interactions with fantail and signal crayfish; water quality	Determine distribution, abundance, and relative abundance in mainstem
Sucker Springs, Pond 3	D	Y(S)	PG&E, leased to CDFG for Pit River Hatchery	Fishery management practices; shortage of lava cobble/boulder substrate; further signal crayfish invasions and interactions	Install barrier at downstream end of Pond 3; signal crayfish eradication; substrate additions
Sucker Springs, Ponds 4 and 5	D	Y (S)	PG&E, leased to CDFG for Pit River Hatchery	Fishery management practices; shortage of lava cobble/boulder substrate; further signal crayfish invasions and interactions	Install barrier at downstream end of Pond 3; signal crayfish eradication; substrate additions
Pit River Sand Pits	E?	Y (S)	PG&E	Interactions with signal crayfish; water quality	Determine distribution, abundance, and relative abundance in mainstem; install exclusion fencing

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Hat Creek, Cassel					
Crystal Lake southwest springs	D	Y (S)	PG&E	Further signal crayfish invasions and interactions	Install barrier at outflow; signal crayfish eradication; install exclusion fencing around Crystal Lake
Crystal Lake middle cove	D	Y (S)	PG&E	Further signal crayfish invasions and interactions	Install barrier at outflow; signal crayfish eradication; install exclusion fencing around Crystal Lake
Crystal Lake outflow	D	Y (S)	PG&E	Further signal crayfish invasions and interactions	Install barrier at outflow; signal crayfish eradication; install exclusion fencing around Crystal Lake
Baum Lake	NS	Y (S)	PG&E		

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Rising River					
Rising River Ranch Bridge	S or D?	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Footbridge	S or D?	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Outflow Channel	S	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Lake	S or D?	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

(1996c) provides an in-depth history of all investigations involving Shasta crayfish and a history and list of all known museum collections of Shasta crayfish.

Land Ownership. Most of the Shasta crayfish populations, including the largest populations, are located on private land. Pacific Gas and Electric Company (PG&E), probably the largest landowner of waterfront property in the midsections of the Pit River drainage, owns property along the Pit River, including Sucker Springs Creek, and in the upper Tule River drainage and portions of the lower Hat Creek drainage (including property along Hat Creek, Crystal Lake, and Baum Lake). PG&E also leases some of their property to CDFG, including Sucker Springs Creek and property along Crystal and Baum Lakes to operate the Crystal Lake Hatchery. California Department of Parks and Recreation (CDPR) owns land in the upper Tule River drainage (i.e., Ahjumawi Lava Springs State Park). Most of the Bear Creek drainage, which is managed as timberlands, is privately owned. Table 2 summarizes the status, land ownership, current threats, and suggested restoration techniques for all populations of Shasta crayfish by geographic area.

Upper Fall River Population (Thousand Springs). The Fall River, is fed by numerous springs from its origin at Thousand Springs and Dana. In addition, two surface runoff streams, Bear Creek and Dana Creek join Fall River within the first 1.5 kilometers (0.9 mile) downstream of Thousand Springs. The tendency for flash flooding in these subdrainages and their potential for producing large amounts of sediments have significantly influenced some of the Shasta crayfish subpopulations in recent decades. Although the Shasta crayfish population in the upper Fall River is fragmented and divided into a number of disjunct subpopulations, genetic exchange is possible and even likely among some of these subpopulations. Genetic exchange between more distant subpopulations becomes increasingly doubtful. Because Shasta crayfish generally do not move great distances (Erman *et al*. 1993, Ellis 1991 unpubl. data, pers. observ.), except in cases where they are washed downstream by the current, the occurrence of genetic

Table 2. Shasta crayfish population status, ownership, threats, and suggested restoration actions (Figures 1 and 3).

Population / Subpopulation	Status[1]	Nonnative Invasion[2]	Owner	Threats	Suggested Restoration
Rising River					
Rising River Ranch Bridge	S or D?	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Footbridge	S or D?	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Outflow Channel	S	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management
Rising River Lake	S or D?	N	Private, restricted access; managed as wildlife refuge	Invasion of signal crayfish	Install barrier upstream of confluence with Hat Creek; support landowner's management

[1] S= stable; D= decreasing; PS= presumed stable; NS= not self-sustaining; E= extirpated
[2] N=no; Y=yes; S=signal crayfish; F= fantail crayfish

(1996c) provides an in-depth history of all investigations involving Shasta crayfish and a history and list of all known museum collections of Shasta crayfish.

Land Ownership. Most of the Shasta crayfish populations, including the largest populations, are located on private land. Pacific Gas and Electric Company (PG&E), probably the largest landowner of waterfront property in the midsections of the Pit River drainage, owns property along the Pit River, including Sucker Springs Creek, and in the upper Tule River drainage and portions of the lower Hat Creek drainage (including property along Hat Creek, Crystal Lake, and Baum Lake). PG&E also leases some of their property to CDFG, including Sucker Springs Creek and property along Crystal and Baum Lakes to operate the Crystal Lake Hatchery. California Department of Parks and Recreation (CDPR) owns land in the upper Tule River drainage (i.e., Ahjumawi Lava Springs State Park). Most of the Bear Creek drainage, which is managed as timberlands, is privately owned. Table 2 summarizes the status, land ownership, current threats, and suggested restoration techniques for all populations of Shasta crayfish by geographic area.

Upper Fall River Population (Thousand Springs). The Fall River, is fed by numerous springs from its origin at Thousand Springs and Dana. In addition, two surface runoff streams, Bear Creek and Dana Creek join Fall River within the first 1.5 kilometers (0.9 mile) downstream of Thousand Springs. The tendency for flash flooding in these subdrainages and their potential for producing large amounts of sediments have significantly influenced some of the Shasta crayfish subpopulations in recent decades. Although the Shasta crayfish population in the upper Fall River is fragmented and divided into a number of disjunct subpopulations, genetic exchange is possible and even likely among some of these subpopulations. Genetic exchange between more distant subpopulations becomes increasingly doubtful. Because Shasta crayfish generally do not move great distances (Erman *et al.* 1993, Ellis 1991 unpubl. data, pers. observ.), except in cases where they are washed downstream by the current, the occurrence of genetic

exchange is probably greater in, if not restricted to, the downstream direction. Consequently, populations at the extreme ends may be genetically distinct from each other.

Spring Creek Population. Spring Creek is a large, spring-fed tributary to the upper Fall River (Meinzer 1927). Spring Creek has the largest population of Shasta crayfish, estimated at over 4,000 individuals, which is found upstream of the four culverts at the Spring Creek Road crossing. The culverts at the Spring Creek Road crossing appear to create a combination physical/velocity barrier to the upstream invasion of signal crayfish, which were found immediately below the crossing.

Shasta crayfish were first reported at Spring Creek in 1978 (Daniels 1980) and as recently as 1993 (Ellis and Gelder unpubl. manuscript). Shasta crayfish were found in the spring-fed coves with lava substrate on the western side of Spring Creek. Genetic exchange is probably occurring between crayfish in the upper coves (Erman *et al.* 1993). The distribution of both lava substrate and Shasta crayfish was probably once more continuous throughout Spring Creek than it is now.

Lava Creek Population. Four large, spring-fed, lava sinkhole pools feed into Lava Creek, which feeds into the Little Tule River at Eastman Lake. The east and west arms of the creek meet 500 meters (0.4 mile) above the Lava Creek outflow, the point where Lava Creek flows into Eastman Lake. Shasta crayfish have been found throughout Lava Creek wherever there was suitable lava habitat (Ellis 1996c). Because lava substrate is found throughout most of the stream, Shasta crayfish once had an almost continuous distribution throughout Lava Creek. When McGriff surveyed Lava Creek in 1985, the spillover into Eastman Lake seemed to act as a velocity barrier (i.e., the rate of the water flow was apparently sufficient to prevent the upstream migration of signal crayfish). McGriff found signal crayfish immediately below the outflow in Eastman Lake (McGriff unpubl. data).

Upper Tule River Population. The upper Tule River subdrainage is fed by two large spring-fed tributaries: Ja-She Creek (fed by Crystal Springs and Crystal Inlet and springs in the Ja-She Creek headwaters) and Big Lake (fed by Big Lake Springs and springs in North Big Lake). The spring-fed Tule Coves feed into the Tule River east of the confluence of Ja-She Creek. Shasta crayfish in the upper Tule River were found in two distinctly different habitats, which have only lava substrates in common: the headwater spring areas or the man-made levees. The spring areas were characterized by constant temperature, flow, and clarity, and the lava substrate in the immediate spring areas was clean with relatively little silt. The headwater spring areas of the upper Tule River are either part of or border Ahjumawi Lava Springs State Park. Shasta crayfish were also found in northeast Big Lake and northwest Big Lake bordering Ahjumawi Lava Springs State Park. Although these areas do not seem to be spring-fed, there is accessible lava substrate for the crayfish. These areas may have been associated with springs that are currently dry. A few Shasta crayfish have also been observed under the cobbles and large boulders along the east shore of Big Lake. Shasta crayfish on the south shore of Big Lake and the shores of the upper Tule River were associated with the levee system built at the turn of the century; most were found under lava rocks imported in the 1930's to help maintain and reinforce the levees. Shasta crayfish were found on the maintained levees along PG&E's McArthur Swamp (Figure 1) and on the old levees bordering Ahjumawi Lava Springs State Park land, on the south shore of Big Lake and along the north shore of the upper Tule River.

Fall River, Fall River Mills (Fall River Pond) Population. Although Shasta crayfish survived the diversion of the Fall River in 1922 and the construction of the Pit 1 Forebay in 1945, the species probably no longer exists at this location (Figure 5). Since the diversion, habitat for Shasta crayfish has probably been marginal. It is an almost stagnant, generally eutrophic body of water, with large daily and seasonal fluctuations in water temperature (5–26 degrees Celsius), an overabundance of aquatic vegetation, and large daily fluctuations in dissolved

oxygen. There is an abundant population of nonnative fish, including largemouth bass and green sunfish, both crayfish predators, and bluegill. Largemouth bass may not have been introduced until sometime between 1974 and 1978 (Daniels 1974 and 1978 unpubl. data, Eng and Daniels 1982). The last detections at this location were of one live Shasta crayfish in 1974 (Daniels 1974 unpubl. data) and one dead one in 1978 (Daniel, 1978 unpubl. data). No Shasta crayfish were found during surveys between 1990 and 1995 (Ellis and Hesseldenz 1993, Ellis 1996c). Both species of nonnative crayfish, signal and fantail crayfish, are found in Fall River Pond.

Pit River Population. Shasta crayfish were once probably present in areas of suitable habitat throughout the Pit River between Fall River and Hat Creek, an area fed by numerous springs and a large, spring-fed tributary, Sucker Springs Creek. Although disturbance and destruction of habitat and the invasion of nonnative species have probably reduced the suitability of much of this habitat, Shasta crayfish have been found in three locations in the mainstem Pit River (two upstream and one downstream of the Pit 1 Powerhouse) and in Sucker Springs Creek (downstream of the Pit 1 Powerhouse).

The only historical records of Shasta crayfish in the mainstem Pit River were from the Pit River sand pits in 1978 (Daniels unpubl. data) and at the outflow of a spring in the Pit River canyon in 1980 (Eng unpubl. data). Daniels (unpubl. data) found eight Shasta crayfish, as well as fantail crayfish, in the mainstem Pit River near the sand pits below the State Highway 299 bridge on three dates in 1978; only signal crayfish were found in this area in a 1995 survey (Ellis 1996a). One dead juvenile male Shasta crayfish was found near a small spring upstream of the Pit 1 Powerhouse in 1980 (M. Rode, pers. comm. 1995). Although Eng suggested that this crayfish might be from Sucker Springs (Eng and Daniels 1982), it is unlikely that this crayfish traveled almost 2.5 kilometers (1.5 miles) upstream through almost 2 percent gradient rapids. In August 1995, one dead juvenile male Shasta crayfish was found under a cobble in the outflow area of the

spring (Ellis 1996a). In addition, both signal and fantail crayfish were found (Ellis 1996a). In 1995, four Shasta crayfish were found in slow water immediately upstream of the Pit River Falls (Ellis 1996a). Fantail crayfish were fairly numerous in the area as well (Ellis 1996a).

Downstream from the Pit 1 Powerhouse, Sucker Springs Creek has a population of Shasta crayfish that has probably been isolated from the Fall River and Hat Creek populations so that it represents a unique gene pool. Although Shasta crayfish have been found in the three downstream ponds (Ponds 3, 4, and 5) of the CDFG Fish Hatchery, the current distribution of Shasta crayfish is mostly restricted to the spring area in Pond 3 (Ellis 1996b).

Hat Creek, Cassel Population. Hydroelectric development of the area has changed lower Hat Creek downstream of the town of Cassel. Crystal Lake, a spring-fed tributary near Cassel, however, remains mostly unmodified and now supports a Shasta crayfish population invaded by signal crayfish. Hat Creek below the outflow from Crystal Lake has since been impounded to form Baum Lake. The occasional Shasta crayfish found in Baum Lake below the outflow from Crystal Lake are probably wash-downs from Crystal Lake (Ellis 1994a). The Shasta crayfish in Baum Lake are probably not a self-sustaining subpopulation. Signal crayfish are very abundant near the inflow from Crystal Lake and common throughout the rest of Baum Lake (Ellis 1994a).

Rising River Population. The Rising River subdrainage is the largest contributor of water to Hat Creek. The springs that form Rising River and Rising River Lake are fed by snow melt from Lassen Peak. Although most of the spring areas in Rising River and Rising River Lake (Figure 3) appear to have good habitat for Shasta crayfish with an abundance of lava substrate, no Shasta crayfish were found associated with any of the springs in the Rising River subdrainage (Ellis 1995). During 1994 surveys (Ellis 1995), two new locations of Shasta crayfish, both associated with bridge sites, were found in the mainstem of the Rising River upstream from the Rising River Lake outflow channel.

G. Reasons for Decline and Current Threats

Although settlers of European descent did not come to the Pit River drainage until the mid-1800's, human disturbance since that time has resulted in considerable habitat destruction and fragmentation. The Pit River drainage has been prized for its hydroelectric power potential since 1875 (Scupman 1875). The water power potential of the Fall River was the major reason the town of Fall River Mills was founded. Development of the Fall River and Hat Creek valley for hydroelectric production began in 1920. Major land reclamation and water diversion projects for agriculture and cattle grazing began even earlier in the Fall River Valley. The introduction of nonnative species of fish and crayfish into the drainage has also had a significant negative impact on Shasta crayfish. Many species of fish introduced in the area prey on crayfish (Table 1). The introduced crayfish are potential predators and competitors of the Shasta crayfish. In addition, natural disturbances resulting from the eruptions of Lassen Peak, floods, and drought have likely had a significant impact on Shasta crayfish.

Land Reclamation

As early as 1903, the McArthur family of Fall River Valley began construction of the approximately 20 kilometers (12 miles) of levees to reclaim 18 square kilometers (7 square miles) of marshland for agriculture and cattle grazing. These levees confine Big Lake, Tule River, and Little Tule River in their present channels. The effect of this land reclamation project on Shasta crayfish has been mixed. The lava rock imported to reinforce the levees created additional habitat for Shasta crayfish. The dredging generally used to build and maintain the levees and the cattle grazing on the reclaimed swamp land, however, has resulted in the degradation or loss of Shasta crayfish habitat through increased siltation, loss of riparian habitat, bank destabilization, and eutrophication of the system.

Shasta crayfish were first noted on the levees along the south shore of Big Lake in 1978 (Daniels unpubl. data, Eng and Daniels 1982). During surveys conducted

for PG&E in 1991 and 1992, Shasta crayfish were found under the lava rocks and boulders on the abandoned levee separating Horr Pond from Tule River at the boundary of Ahjumawi Lava Springs State Park, as well as the south shore of Big Lake (Ellis 1991a, 1993a, Ellis and Hesseldenz 1993). Shasta crayfish were also found on the levees along the upper Tule River, even though most of the lava rocks in this area have been buried or embedded by later dredging. Shasta crayfish along the south shore upper Tule River showed remarkable flexibility in their use of existing habitat by utilizing burrows, wood, and the few accessible lava rocks as refugia.

Hydroelectric Development

Hydroelectric development, including the operation of four powerhouses in the midsections of the Pit River represented the first broad scale disturbance to the Shasta crayfish population. Lava cobble and gravel substrate in the drainage were undoubtedly more abundant historically than they are now. The range of Shasta crayfish and other aquatic species was divided into at least five subdivisions by 1922 (as previously discussed under "Current Distribution and Population Status") due to habitat alterations, such as excavations, river impoundments, water diversions, inundations, and changes and reductions of flows.

Some secondary effects resulting from hydroelectric operations and management in the area include increased siltation and water temperature and decreased dissolved oxygen content in associated bodies of water. The Pit 1 Powerhouse, which impounded and/or dewatered regions where Shasta crayfish were found in the Fall River at Fall River Mills (type locality), subjects the Pit River downstream to daily fluctuations in flow that result in over a meter (3 feet) difference in the height of water, dewatering the margins. These daily fluctuations create a freshwater "intertidal" region with few organisms adapted to take advantage of the changing habitat. Shasta crayfish upstream of the Pit 1 Powerhouse have a reduced flow.

Introduced Crayfish

Within the last two decades, two species of nonnative crayfish have been introduced into the midsections of the Pit River drainage: signal crayfish and fantail (virile) crayfish. The introduction of both species is thought to have been the result of angling and the use of crayfish as bait (Eng and Daniels 1982).

Although fantail crayfish were the first nonnative crayfish to be introduced into the area (Bouchard 1977a), they have since been replaced throughout most of their range by signal crayfish. Fantail crayfish are potential competitors of Shasta crayfish in the newly discovered subpopulation in the Pit River (Ellis 1996a) upstream of the Pit 1 footbridge. Interactions between Shasta crayfish and fantail crayfish have not been studied.

The signal crayfish has rapidly expanded its range throughout most of the drainage and occurs with Shasta crayfish in at least a portion of five of the seven populations. The rapid expansion of signal crayfish has been linked to the diminished distribution of Shasta crayfish within their range (Ellis 1996d). Signal crayfish have all the characteristics of a classic invading species (Ehrlich 1989); they are larger, more aggressive, faster growing, earlier maturing, produce more offspring (Figure 6, Table 3, Abrahamsson 1971; Flint 1975; Goldman *et al.* 1975; Fürst 1977; Eng and Daniels 1982; Ellis, pers. observ.) and have a larger native range than Shasta crayfish. Signal crayfish also have a broader diet, greater physical tolerance (e.g., to water temperature and quality), and a higher daytime activity rate than Shasta crayfish (Ellis and Hesseldenz 1993). In contrast, Shasta crayfish are slow growing, with a long generation time, a small native range, a relatively restricted diet, a narrower tolerance range of physical conditions, and a smaller body size at all ages than signal crayfish (Table 3, Figure 6; Daniels 1980; Eng and Daniels 1982; Ellis, pers. observ.). Signal crayfish generally are twice the size of Shasta crayfish at each age class (Figure 6), primarily due to a faster growth rate that gives signal crayfish a competitive advantage over Shasta crayfish of the same age. Additionally, signal crayfish become free-living days to

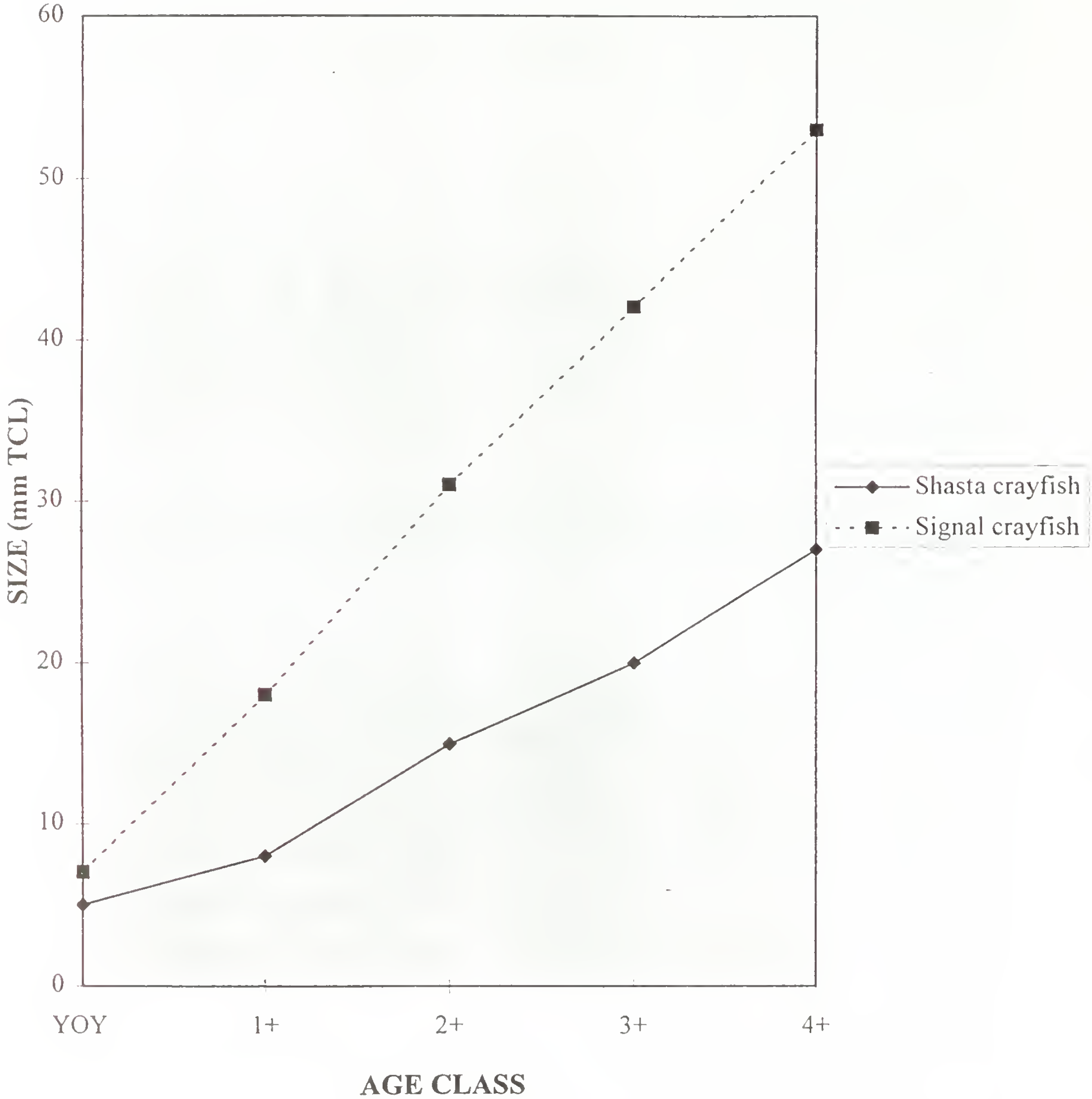


Figure 6. Ontogenetic (developmental) changes in body size of Shasta crayfish and signal crayfish (from Ellis 1991b).

Table 3. A summary and comparison of the life history traits of Shasta crayfish and signal crayfish in the midsections of the Pit River drainage.

Life History Trait	Shasta crayfish	Signal crayfish
Maximum Size[1]	58.70 mm (2.35 in)	74.65 mm (3.0 in)
Mean Size	26 mm (1.04 in)	28–54 mm (1.12–2.16 in)
	Sexual Maturity	
Female Age	5th year	2nd–3rd year
Female Size	27 mm (1.08 in)	36 mm (1.44 in)[3]
Male Age	5th year	2nd–3rd year[2]
Male Size	—	36 mm (1.44 in)[3]
Reproduction	one brood/season	one brood/season
Mating Season	late Sept/Oct	late Sept/Oct
Spawning	Oct/Nov	Oct/Nov
Number of Eggs	10–70 eggs/female	20–200 eggs/female
Egg Diameter	3.1–3.45 mm (0.12–0.14 in) Average = 3.3 mm (0.13 in)	2.3–3.0 mm (0.09–0.12 in)
Egg Hatching	late May/early July	May
First Instar	attached, 4–5 mm	attached
Second Instar	clinging with claws 5–7 mm (0.20–0.28 in) late June	clinging with claws May/early June
Third Instar	free-living 5–7 mm (0.20–0.28 in) mid-late July	free-living 7–9 mm (0.28–0.36 in) early June
Young Of the Year (YOY)	7–8 mm (0.28–0.32 in)	13–16 mm (0.52–0.64 in)
End of Season	October	October
	Size Classes	
0+	5–8 mm (0.20–0.32 in)	7–17 mm (0.28 –0.68 in)
1+	8–14 mm (0.32–0.56 in)	18–30 mm (0.72– 1.2 in)
2+	15–19 mm (0.60–0.76 in)	31–41 mm (1.24–1.64 in)
3+	20–26 mm (0.80–1.04 in)	42–52 mm (1.68–2.08 in)
4+	adult 27 mm (1.08 in)	53–64 mm (2.12–2.56 in)
Growth	1–3 mm (0.04–0.12 in)/molt	5–10 mm (0.20–0.40 in)/molt[3]

Source: adapted from Ellis and Hesseldenz (1993)

[1] All lengths reported as total carapace length (TCL) (1 millimeter [mm] = 0.04 inch [in])

[2] *Pacifastacus leniusculus* in Berry Creek (Mason 1975)

[3] *Pacifastacus leniusculus* in Sacramento-San Joaquin Delta (McGriff 1983)

weeks before Shasta crayfish (Ellis, pers. observ.). Signal and Shasta crayfish populations use the same rocks for refuge and eat many of the same foods (exploitative competition) (Ellis 1993b). Signal crayfish are aggressive and cannibalistic, and Shasta crayfish do not change their behavior to avoid signal crayfish (Ellis in prep., Ellis 1996d), making Shasta crayfish vulnerable to competition and predation.

There has been considerable concern about hybridization between Shasta and signal crayfish. There has been no evidence, however, of any hybrid offspring in any of the populations, including Crystal Lake, which was invaded by signal crayfish in 1978. The more aggressive signal crayfish males probably mate with nonaggressive female Shasta crayfish where they occur together. The absence of hybrid individuals, however, indicates that only nonviable eggs are produced from matings between the two species, which could effectively reduce the reproductive output of the female Shasta crayfish to zero for the year (reproductive interference). This type of reproductive interference can be costly to Shasta crayfish because they are slow growing, late maturing, and have low fecundity (produce fewer offpring). Reproductive interference in conjunction with differences in aggression and susceptibility of young crayfish to predation were major factors in the replacement of one species by another species of crayfish (Butler and Stein 1985).

Potential Crayfish Pathogens

There is always a danger that the introduction or invasion of a new species will be accompanied by the introduction of other organisms, such as pathogens, parasites, and commensals (an organism that may derive some benefit from living on another organism, but neither harms nor is parasitic on its host). The transfer of parasites and diseases with the introduction of exotic species can have catastrophic consequences, such as the crayfish plague in Europe. In this case, the introduced species was resistant to the pathogen it carried, so that only the native species was devastated (Unestam 1973, 1975, von Broembsen 1989). Organisms

that are harmless to their host species in its natural environment may become aggressive in a new environment or when introduced to a new species (Unestam 1975, von Broembsen 1989). Almost half of the locations where Shasta crayfish are currently found also have signal crayfish (Lowery and Holdich 1988; see also Tables 2 and 4), which carry many diseases and pathogens that are probably foreign to Shasta crayfish (Ellis 1994b).

One type of segmented worm, or annelid (Phylum Annelida), is the branchiobdellidan worm, a commensal that lives on crayfish but generally does not harm the crayfish host. The worms may be found on the claws, or chelae, in or around the gill chambers, or on the mouthparts of signal crayfish. Only one species of this worm has been documented to be parasitic on crayfish (Grabda and Wierzbicka 1969).

Two species of these worms, *Magmatodrilus obscurus* and *Sathodrilus shastae* (Goodnight 1940, Holt 1967, 1981), are known only from Shasta crayfish (Ellis 1996d). The former species was generally present in all Shasta crayfish populations and abundant in many (Ellis 1996d). The latter species was only common on Shasta crayfish in the outflow channel of Rising River Lake, and three specimens were found on one Shasta crayfish in Crystal Lake (Ellis 1996d). Three species of these worms have been found on signal crayfish within the range of Shasta crayfish: *Xironogiton victoriensis*, *Cambarincola gracilis*, and *Sathodrilus attenuatus*. The first two of these species were also found on Shasta crayfish (Crystal Lake, mainstem Fall River, Sucker Springs Creek, and Lava Creek), but *Xironogiton victoriensis,* the most abundant species found on signal crayfish, was found most often on both Shasta and signal crayfish where the two species occur together (Ellis 1996d). This species was found on Shasta crayfish in five of the six locations where they occurred with signal crayfish.

The introduction of new species of these worms to Shasta crayfish provides another potential source of pathogens and parasites (Hobbs *et al.* 1967), as branchiobdellidan worms show evidence of having parasites of their own and are intermediate hosts for the eggs and larvae of other parasitic worms (Unestam 1969, Brinkhurst and Gelder 1991). Signal crayfish in California also carry parasites that have never been documented in Shasta crayfish (McGriff and Modin 1983).

Signal crayfish carry several diseases, including those resulting from fungal (crayfish plague), protozoan, bacterial, and viral agents. Signal crayfish both carry and are resistant to the fungus that causes crayfish plague. Apparently, the resistance of Shasta crayfish to crayfish plague has never been tested (Unestam 1969). Recently, a new virus was discovered in signal crayfish (Hedrick 1995), but the effects on the host are unknown (Groff *et al.* 1993, Hedrick, pers. comm. 1994). The virus was found in signal crayfish from Crystal Lake in the Hat Creek drainage of northeastern California, but was not found in signal crayfish from Ja-She Creek (Fall River drainage). Additional research will investigate the potential relationship between the decline in Shasta crayfish with the recently reported viral infections in signal crayfish (Hedrick 1995).

Entocytherid ostracods, freshwater crustaceans (mussel or seed shrimp) that depend on their hosts as sites for reproduction and rearing of young (Young 1971), are commensals on crayfish. Peritrich ciliates (Phylum Ciliophora) are protozoans that are often found colonizing the external surface of both Shasta and signal crayfish giving the crayfish a “furry” appearance (Ellis, pers. observ.). Diatoms (Division Chrysophyta) and blue-green algae (Division Cyanophyta) are common on the exterior surface of crayfish (Hobbs *et al.* 1967; Holt 1986; Ellis, pers. observ.).

Sedimentation

Sedimentation in the midsections of the Pit River drainage has been caused by a combination of activities including: 1) hydrologic alterations, 2) channelization, 3) dredging, 4) logging, 5) forest fires, 6) agriculture, 7) grazing, and 8) muskrat activity.

Hydrologic alterations. Alterations in the natural hydrology of the Pit River drainage have increased the amount of both organic and inorganic sediment in the system. Old maps of the Fall River drainage show the only open water in the upper Tule River/Big Lake drainage was McArthur Lake, a small lake located at the spring-fed north end of Big Lake. The area now covered by the rest of Big Lake, Horr Pond, Tule River, and McArthur Swamp was an immense wetland, and portions were probably maintained as a year-round wetland. The original hydrology of the Tule River subdrainage is unknown.

Channelization. With its drainage area of 217 square kilometers (84 square miles), Bear Creek is the only major sediment source in the Fall River system. Prior to its channelization around 1960, Bear Creek meandered gradually through the meadow at the lower end of its watershed until it flowed into Dana Creek. The sinuous channel and broad floodplain moderated the impacts of high-water flows and allowed the meadow to accumulate and store much of the sediment brought down from the upper watershed.

As a result of channelization, the meadow became a source of sediment as Bear Creek cut down through its bed and banks. High flows in Bear Creek in 1986 and in subsequent flood events resulted in the movement of a large quantity of sediment (gravel, sand, and silt) from the Bear Creek watershed that continues to impact the upper Fall River (Ellis and Hesseldenz 1993). The steady migration of this sediment downstream has covered patches of aquatic vegetation with silt. Patches of Bear Creek gravel have buried crayfish and sculpin habitat. Below the

mouth of Bear Creek where the river gradient is higher, the deposits of Bear Creek gravel are relatively free of fine sediment and provide substantial trout and sucker spawning habitat. Patches of substrate clear of Bear Creek sediment in the upper Fall River, in particular near bends and channel constrictions, (Ellis, pers. observ.) indicate that the flow of water in some areas is sufficient to move sediment. In these areas of clean substrate, the aquatic vegetation appears to be recovering.

The movement of sediment from Bear Creek has not been brought under control and continues to pose a threat to mainstem Fall River. Given the low gradient of the mainstem Fall River, it will be many years, if ever, before Bear Creek sediments already in the river are completely flushed through the system. Shasta crayfish were probably once found throughout the upper Fall River wherever lava substrate was present. Bear Creek sediments may have buried former Shasta crayfish subpopulations and habitat in the upper Fall River. The two locations in the mainstem Fall River where Shasta crayfish were found in 1990–1993 are in serious danger of destruction. These mainstem Fall River subpopulations face continued and compounded threats because of mobile sediments and crowding by signal crayfish into these "islands" of higher quality substrate preferred by both species.

The section of Hat Creek upstream from the confluence with Rising River was channelized in the 1950's by the Army Corps of Engineers (COE), in joint venture with private property owners. The Army Corps of Engineers undertook the project because farmers and ranchers in the area were complaining that sediment was inundating their water diversions. Before channelization, this 4.8 kilometer (3 mile) section of Hat Creek had multiple channels that allowed sediment to be deposited on the creek's flood plain. Channelization increased the rate of sediment movement out of the upper drainage and deposited the sediment in lower Hat Creek. The sedimentation of lower Hat Creek covered lava gravel, cobbles, and boulders with fine sediment. The section of Hat Creek between the

confluence of Rising River and the town of Cassel changed dramatically as the riffle filled in and the section immediately above it became a braided channel and lagoon (L. Kerns, pers. comm. 1997). The crayfish, bivalves, fish, and river otters all disappeared from the lower section after Hat Creek was channelized (L. Kerns, pers. comm. 1996).

Dredging. Beginning in 1903, approximately twelve miles of levees were constructed to hold Big Lake, Tule River, and Little Tule River in their present configuration. Damage to the levees by floods, wind and wave erosion, cattle grazing, and muskrat activity have required numerous repairs over the last 90 years. Between 1903 to the present, the levees were primarily repaired using material dredged from the bottom of the lake and rivers. During two periods, 1915–1940 and 1952–1962, there was no dredge in operation so repair and maintenance of the levees was accomplished using imported materials including basalt lava gravel, cobble, and boulder material.

Dredging operations can bury benthic organisms, particularly species with lower mobility. If material is deposited on the water side of the levees, lava substrate can be buried. A decrease in the amount of basalt lava substrate where it is already limited, such as the south shore Tule River, results in a significant loss of habitat for Shasta crayfish and other species that depend on that substrate. Dredging operations also increase the amount of suspended particulates in the water, which increases turbidity and sedimentation in the vicinity of the dredging operations and downstream.

Logging. Past forest practices have contributed sediment to Bear Creek. Although Bear Creek's flow is intermittent and seasonal, it is the primary source of surface runoff into the Fall River and has contributed substantial sediment to the upper Fall River in recent decades. The major part of the Bear Creek watershed has been well managed; however, some past timber harvest practices have focused on short-term, high-extraction, high-profit methods. Other activities

that are associated with timber harvesting have also contributed sediment, such as road construction and use and repeated failures of a railroad culvert in the upper watershed of the south fork in 1986 and 1997. The repeated railroad culvert failures caused extreme peak flows, which degraded the stream downstream of the culverts.

Forest Fires. Burns and the salvage logging operations that generally follow have the potential to contribute sediment. Most of Fall River and Hat Creek flow through nonforested valley floors where the risk of impacts from fires is minimal. With the exceptions of a few meadows, however, the entire watershed of Bear Creek was originally forested. In 1977, the Pondosa fire burned roughly 23,000 acres in the mid-watershed of Bear Creek downstream from Pondosa, California. This area was replanted immediately after the burn and appears to be recovering well. The Pondosa burn crossed Bear Creek at only two small sites. There is little evidence of erosion in the area impacted by the Pondosa burn.

Agriculture. The primary land use in the Fall River and Hat Creek valleys is pasture. Land is also cultivated for potatoes, grains, and, most recently, wild rice. Wild rice ponds could be a source of nutrients, pesticides, and sediment for the river contributing to a decline in water quality that would negatively impact the abundance and diversity of aquatic insects and other invertebrates, as well as the fishery. The effects of wild rice farming have not been studied since 1984 when a study determined that rice farming had either unmeasurable or insignificant effects on water quality in the Fall River (Lewis, 1985)

Grazing. The impact of livestock grazing in the riparian zone along the rivers and lakes can be seen throughout the midsections of the Pit River drainage. During the last 5 years, however, significant progress has been made in fencing livestock out of the riparian zone. PG&E fenced the entire McArthur Swamp area from the upper Tule River and Big Lake. Many landowners in the upper Fall River have either fenced their property or are currently working to do so. Cattle

grazing in the meadows of Bear Creek has also had a negative impact on Bear Creek. Two of these meadows, however, have been fenced in the last few years. The riparian zones of one of these meadows (Long Ranch) is already beginning to heal (Ellis, pers. observ.). The impacts of cattle grazing and agriculture have resulted in increased siltation, nutrient loading, and bank and riparian zone destruction, all of which contribute to a loss of lava substrate and habitat.

Muskrat Activity. Muskrats are not native to the midsections of the Pit River drainage or to most of California (Storer 1938). Muskrats were introduced into the Fall River drainage around 1930 from the Mount Shasta Fur Farms on Mud Lake (next to Big Lake) (Storer 1938). By 1938, muskrats were found throughout the Fall River and lower Hat Creek drainages (Storer 1938). The burrowing of muskrats in conjunction with livestock grazing causes bank erosion and loss and contributes sediment to the waterways. Muskrats also prey on crayfish. Muskrat activity along the levees of the upper Tule River has a negative impact on Shasta crayfish. The control and/or eradication of muskrat populations in the watershed would be beneficial to Shasta crayfish.

Geothermal Development

Preliminary data indicates that the Medicine Lake Highlands is the recharge area (source of water) for the Fall River springs (Rose *et al.* 1996). The Bureau of Land Management (BLM) has issued numerous leases for the purpose of exploring and developing a geothermal resource within the Medicine Lake Highlands area since 1981. In the last two years, geothermal development of the Medicine Lake Highlands for power generation has been proposed for two areas: Fourmile Hill Power Plant in 1995 and Telephone Flat Power Plant currently. Another exploratory drilling project within the Glass Mountain Known Geothermal Resource Area was also proposed in 1995. Environmental assessments and Findings of No Significant Impact were prepared for both of the 1995 project proposals. The Alturus Resource Area of the Bureau of Land

Management; U.S. Forest Service (USFS), Modoc National Forest; U.S. Department of Energy, Bonneville Power Administration, and the Siskiyou County Air Pollution Control District are jointly preparing an Environmental Impact Statement/Environmental Impact Report (EIS/EIR) for the proposed Telephone Flat Geothermal Development Project.

If geothermal development or exploration of Medicine Lake Highlands contaminates the freshwater that recharges the Fall River springs system, wide-scale extirpation of most Shasta crayfish populations could result. Because the majority of both populations and individuals of Shasta crayfish are found in the Fall River drainage, the extirpation of the Fall River populations of Shasta crayfish would likely lead to the species extinction.

The interconnection between the shallow freshwater that recharges the Fall River springs system and the deeper geothermal groundwater should be determined before further exploration or development of the Medicine Lake Highlands is done. Perturbations to one of these groundwater systems may result in disturbance of the other (R.Poore, T. Gross, and M. Ellis *in litt.*). The recharge areas and their degree of interconnectivity with the springs in the midsections of the Pit River drainage should be determined. These recharge areas should be protected from all potential disturbances, such as geothermal development and water diversions.

Investigations to determine the origin and subsurface paths of groundwater using isotope hydrology have been conducted for Hat Creek basin (Rose *et al.* 1996) and are proposed for Fall River basin (Davisson *et al.* 1997). Isotopes (atoms of the same element but with slightly different masses) present in water can be highly diagnostic groundwater tracers, providing specific information regarding the water's origin.

Further Water Resource Development

Any proposals for development of the water resources in the area, including the recharge area, that entail diverting, removing, impounding, or otherwise impacting the discharge, temperature, chemistry, or clarity of the water should be thoroughly investigated prior to development. Particular attention should be directed at any developments that would directly impact the discharge, temperature, chemistry, or clarity of the springs or water in the midsections of the Pit River and/or Shasta crayfish habitat, and restrictions on development may be necessary.

Velocity Barriers

Road construction and associated culverts at stream crossings have created velocity barriers at Spring, Lava, and Ja-She creeks that probably act to further subdivide Shasta crayfish within the Fall River drainage. These barriers have served a more beneficial role in the last two decades by at least partially slowing the expansion of signal crayfish into Shasta crayfish habitat.

Fishing and Fisheries Management

Fishing and fisheries management have impacted Shasta crayfish directly or indirectly through five major activities: (1) the intentional introduction of nonnative game fish species to provide sport fishing, with or without the sanction of CDFG and other agencies; (2) the introduction of nonnative crayfish species through the use of bait; (3) the restoration and improvement of wild trout habitat; (4) the management of hatcheries and hatchery trout; and (5) crayfishing. Individually, none of these activities is likely to result in the observed decrease in range and abundance of Shasta crayfish, but the cumulative effect has had a substantially negative impact on the species.

The introduction of exotic species fish and crayfish, with the potential to be predators, competitors, and sources of new diseases and pathogens is probably one of the biggest threats to the continued existence of the Shasta crayfish. Gamefish species, such as brown trout, largemouth bass, smallmouth bass, black crappie, green sunfish, bluegill, black bullhead, brown bullheads, and channel catfish have all been introduced into the midsections of the Pit River drainage and all prey on crayfish (Crocker and Barr 1968, Taub 1972, Rickett 1974). Common carp have also been introduced and eat invertebrates living on the river bottom. Largemouth and smallmouth bass and green sunfish, in particular, are voracious predators on crayfish.

Various management strategies such as chemical treatments, fish sampling, and the addition of spawning gravel for wild trout and other game fish have also had an adverse effect on Shasta crayfish. Chemical treatments have been used to reduce the nongame fish population, and rotenone (M. Berry, pers. comm. 1995) and chlorine (Schafer 1968) have been used in Crystal Lake in attempt to eradicate the protozoan *Ceratomyxa*, which infects salmonid fish by invading their organs after being ingested. *Ceratomyxa shasta* is fatal to most nonnative strains of rainbow trout and occurs throughout most of the midsections of the Pit River drainage, including the Fall River drainage, the lower Hat Creek drainage, and the Rising River subdrainage (Schafer 1968) . The native strain of rainbow trout has a much higher resistance to the disease than strains originating in areas free of the parasite. Consequently, Ceratomyxosis has been beneficial in maintaining the genetic integrity of the native rainbow trout in the area.

Shasta crayfish may have been trapped beneath gravel or crushed by heavy machinery when gravel was added at the outflow of Crystal Lake to increase spawning habitat for trout. Heavy machinery, such as backhoes, are sometimes used in the channel for major maintenance or repair of the ponds, such as after the flood of 1986 (L. Draper, pers. comm. 1995).

Sucker Springs Creek, the site of CDFG's Pit River Hatchery (Figure 1), has been periodically sampled by electroshocking and has been salted to kill snails (Richard L. Elliott *in litt.*). The weirs in Sucker Spring Creek are concrete structures that hold up to four, 6- or 8-foot long, wooden flashboards. The purpose of the flashboards is to back up water in the channel to increase the water depth, before allowing the water to flow over the flashboards. The weirs used to separate the different ponds within the hatchery have helped to slow the upstream invasion of signal crayfish. However, removing the flashboards from the weirs for hatchery maintenance has had severe impacts on Shasta crayfish by dewatering habitat and allowing the invasion of signal crayfish into a pure Shasta crayfish population.

There are no records of the extent or impacts of crayfishing that occurred either historically from the Pit River Indians and early settlers or in more recent times. In an attempt to protect Shasta crayfish, the midsections of the Pit River have been closed to crayfishing and the use of crayfish as bait since 1981. Some areas are now open for crayfishing where the introduced species are abundant (e.g., the Fall River downstream of the confluence of Tule River, including Pit I Forebay, Fall River Pond, and Lake Britton), but the restriction on the use of crayfish as bait remains. Other activities related to fishing and fisheries management mentioned above probably have a greater effect on Shasta crayfish than crayfishing.

Natural Disturbances

Hat Creek Mudflow of 1915. On May 19, 1915, lava flowed over the southwest and northeast sides of the crater on Lassen Peak. The northeast flow melted a deep snowbank creating a flood of water, condensed steam, mud, and ash that plunged down the mountainside through Hat Creek and its tributary Lost Creek. The mudflow swept down approximately 30 kilometers (19 miles) of Hat Creek, cutting a 400-meter-wide (0.25 mile) path through forests and ripping bark off

trees almost 6 meters (20 feet) above the ground. The wall of mud demolished cabins and homesteads, crushed trees, and deposited up to 6 meters (20 feet) of mud and debris on fertile meadows (U.S. National Park Service 1974, Schulz 1990).

Although most of the mud was deposited in the upper sections of the Hat Creek drainage, the sheer volume of water and sediment that reached lower Hat Creek probably resulted in considerable scouring and deposition. Shasta crayfish in lower Hat Creek may have been buried in mud or swept downstream by the tremendous mudflow. Since the mudflow of 1915, Shasta crayfish have been documented in the spring-fed lakes feeding into lower Hat Creek, but not in the mainstem itself.

High Flows, Floods, and Drought. The hundred-year flood of 1986 caused the Pit River to overflow its banks, scouring its channel as well as some of the spring-fed tributaries, including Sucker Springs Creek. Although once commonly observed, Shasta crayfish became a rare sight after the flood (L. Draper, pers. comm. 1995). Since the majority of remaining Shasta crayfish live in the spring-fed headwaters of the drainage, scouring from floods and high-water events is not a serious threat. Shasta crayfish in Sucker Springs Creek, however, have experienced several high-water events from the nearby Pit River, such as the high flows (up to 15,000 cubic feet per second) in the Pit River canyon during the spring of 1995 (U.S. Geological Survey unpubl. data). Although the impact of these high flows on Shasta crayfish in the mainstem Pit River is unknown, Shasta crayfish survived high flows in the Pit River in 1964, 1986, 1993, 1995, and 1996; therefore, the impacts of high flows do not appear to be limiting factors to the survival of Shasta crayfish in the mainstem Pit River.

In 1986, high flows in Bear Creek resulted in flooding of areas in the upper Fall River. The resulting movement of large amounts of sediment from the Bear Creek watershed continues to impact the upper Fall River.

During substantial periods in the last twenty years, a shortage of water has been a common problem. Although it is unclear whether the seven year (1987–1993) drought affected Shasta crayfish populations, the volume of water in the rivers was substantially lower than normal, and several springs were no longer flowing during the last year of the drought. Although the base flow in the Fall River is generally around 1400 cubic feet per second, it was only 675 cubic feet per second before the drought ended (Rose *et al.* 1996). Because flushing is reduced when flows decrease, the rate of siltation and the resultant loss of habitat would have increased throughout the Pit River drainage during this period. Lava substrate in areas where the springs have stopped flowing, rapidly becomes silted over without the flushing provided by the spring flow.

Habitat Changes and Threats To Individual Populations

Table 2 details current threats to individual populations or subpopulations, in addition to providing information on the status of Shasta crayfish at each site, ownership, and suggested restoration.

Upper Fall River. The spring areas in the upper Fall River are generally pristine with an abundance of good to excellent Shasta crayfish habitat. In many cases, such as Thousand Springs, the potential Shasta crayfish habitat is much more extensive than the habitat actually used.

There are two major threats to Shasta crayfish in the Upper Fall River drainage: losses of Shasta crayfish and their habitat due to sedimentation from Bear Creek and the movement of signal crayfish up the Fall River. Sedimentation from Bear Creek (previously discussed under "Reasons for Decline and Current Threats") covers lava-cobble-on-lava gravel substrate characteristic of the best habitat throughout the upper Fall River drainage, which includes the two mainstem Fall River subpopulations of Shasta crayfish. Sedimentation in a kilometer (0.62 mile) of good-to-excellent Shasta crayfish habitat between the headwaters and Rainbow

Spring has restricted contact between the two subpopulations separated by this section and affected the exchange of genetic material (gene flow) between them. Shasta crayfish are prone to being entombed by highly mobile sediments. Downstream from Bear Creek, Shasta crayfish were only found where there was no Bear Creek gravel, such as in the sand springs area.

The other major threat to the upper Fall River is the invasion of the introduced signal crayfish, which have already reached the outflow of Rainbow Spring. An old dam at the outflow of Rainbow Spring creates a barrier to keep signal crayfish from migrating into Rainbow Spring. There are no barriers to prevent signal crayfish from reaching Thousand Springs (although Bear Creek sediments may have slowed their progress somewhat).

Although there has been grazing on Thousand Springs in the past, all livestock has been restricted from the riparian zone for the past 7 years. Proper land management including stream bank protection, i.e., cattle grazing/fencing issues, and maintaining a healthy riparian zone, i.e., timber management, remain important issues downstream from Thousand Springs and in the Bear Creek drainage.

There has been a proposal from the private sector to suction dredge the entire 8 kilometer (5 miles) section of the Fall River between the Navigation Limits and Spring Creek Road, to remove a minimum of 272,000 cubic yards of sediment from the channel. Suction dredging a large section of river would constitute a large-scale perturbation to the aquatic animal and plant communities. A suction dredger would result in the direct mortality of any benthic organisms, such as Shasta crayfish, that were suctioned. Stabilization of the sediment source in the Bear Creek watershed and restoration of the floodplain in the Bear Creek meadow (see Conservation Measures) should be given first priority. Limited suction dredging may then be a potentially useful tool for removing sediment from certain sections of the river where sediment accumulates and where the impact on aquatic plant and animal community is minimal.

Spring Creek. The property along Spring Creek is leased as a working cattle ranch. Some seasonal grazing allowed in the riparian zone has been of short duration and restricted primarily to lava flow areas as compared to bank areas composed of organic material. There seems to have been little damage to the stream banks. Current threats include a shortage of lava cobble/boulder substrate and the invasion of signal crayfish.

Lava Creek. Shasta crayfish apparently no longer occupy two ponds in upper Lava Creek as a result of predation from introduced largemouth bass and from siltation and eutrophication resulting from habitat disturbance and destruction due to drought, human activities, and an abundance of waterfowl. Additional sediment has entered Lava Creek from past agricultural uses, including an extensive pig farm that was once located on the fields adjacent to the outflow. Current land uses include growing alfalfa on laser-leveled fields, which are periodically flood-irrigated. Most of the lava substrate has been covered with organic sediment and silt.

The principal current threat is signal crayfish invasion. Shasta crayfish in the east and west arms of Lava Creek are currently free of signal crayfish. Signal crayfish migrating up from Eastman Lake were found in Lava Creek above the outflow in 1990 and are found between the outflow into Eastman Lake and the point (confluence) where the east and west arms of Lava Creek flow together; the numbers have increased significantly since that time. The upstream expansion of signal crayfish in Lava Creek has been coincident with a drastic decrease and disappearance of Shasta crayfish in the lower sections of Lava Creek.

Tule River. All of the lava gravel, cobble, and boulder material associated with the levees is assumed to have been imported for the repair and maintenance of the levee system. Until recently, the combination of extensive cattle grazing and wind caused extensive erosion on the levees. During the last century, this levee erosion combined with the dredging used to repair the eroded levees has produced

a thick layer of silt that has buried much of the lava substrate. PG&E has recently fenced all of their levees along Big Lake and the Tule River so that cattle are excluded from the levees (see Conservation Measures).

Water temperature in the river and lake along the levees is extremely variable both seasonally and daily, ranging from 6–24 degrees Celsius (43– 75 degrees Fahrenheit) (PG&E unpubl. data). There is little to no visible flow of water in the upper Tule River drainage, and it generally becomes very eutrophic during the summer.

CDFG has attempted introductions of brown trout, rainbow trout, white catfish, channel catfish, and brown bullhead into Big Lake, but with limited success. Largemouth bass, known crayfish predators, were also introduced into Big Lake, however, and are thriving. Although largemouth bass is a warmwater species, juveniles tend to use the spring areas as a refuge from larger fish predators, and adults take advantage of this relatively warm environment by overwintering in the spring areas (D. Weidlein, pers. comm. 1996). The presence of largemouth bass in the spring areas may explain the low density of Shasta crayfish found in the springs of the upper Tule River drainage relative to other springs in the Fall River drainage. Current threats include the absence or shortage of lava substrate, dredging, and invasions by and interactions with fantail crayfish and signal crayfish.

Fall River. The construction and operation of the Pit 1 Hydroelectric Project drastically altered the physical characteristics and hydrology of the Fall River through dredging and filling, flooding and impounding, and diversions and alterations of the flow of water. Available evidence indicates that when Rutter and Chamberlain collected Shasta crayfish in the Fall River at Fall River Mills in 1898, there was an abundance of clean lava substrate and rapidly flowing, well-oxygenated water that supported a healthy community of native species. By the time Daniels found Shasta crayfish in the impounded section of the Fall River at

Fall River Mills (Fall River Pond) in 1974 and 1978, available lava substrate had been severely depleted and the river was a stagnant pond with large diurnal fluctuations in oxygen. In addition, the native aquatic community had been almost entirely replaced by nonnative species, including four species of sunfish and bass and two species of crayfish. Shasta crayfish are considered extirpated from this location as none have been found in recent surveys (Ellis and Hesseldenz 1993, Ellis 1996c).

Pit River. Two major impacts to the Pit River include the 1922 diversion of the Fall River to the Pit 1 Powerhouse, which significantly reduced the flow of water through the Pit River canyon, and the construction and operations of the CDFG Pit River Hatchery, a small fish hatchery consisting of five fish ponds in the Sucker Springs Creek channel.

The Pit River Fish Hatchery was built in 1965. Heavy machinery was used to clear most of the lava cobble and boulders, and imported river gravel was placed on the bottom of the ponds. This eliminated any suitable habitat for Shasta crayfish along the center of the channel. Shasta crayfish may have been crushed by the use of heavy machinery during construction and in subsequent pond maintenance activities. Concrete weirs with wooden flashboards were constructed to separate the channel into five separate ponds. These weirs became barriers to the upstream migration of signal crayfish and maintained deeper water in the channel.

A dam across the Sucker Springs Creek upstream has caused siltation and sedimentation, eliminating any remaining Shasta crayfish habitat upstream. The dam has also improved habitat for snails (*Fulminicola* spp.) that are the intermediate host for the gill fluke, a common parasite and cause of hatchery fish mortality.

Fish hatchery management that can negatively effect Shasta crayfish includes removing lava cobbles and boulders and adding large amounts of salt to the creek

and some ponds to eliminate the snail (West 1969, L. Draper, pers. comm. 1996). Shasta crayfish are impacted, not only by the removal of habitat and possibly by the addition of salt, but also the snails being eradicated seem to be a major food resource for Shasta crayfish. Copper sulfate (West 1969), pesticides (Daniels and Moyle 1978), and rotenone have been used for fish hatchery management. Routine electroshocking, used for moving trout between ponds, probably exposes Shasta crayfish to repeated shocks. Crayfish can be killed by prolonged exposure to electroshocking. In addition to fish hatchery management practices, current threats include invasions by and interactions with signal crayfish and fantail crayfish, water quality, and the shortage of lava cobble/boulder substrate.

In 1996 the flashboards between the ponds were removed for almost a month, which allowed the invasion of signal crayfish into a previously pure Shasta crayfish subpopulation in Pond 3. In addition, the removal of the barriers dewatered the majority of suitable habitat for Shasta crayfish and exposed them to terrestrial predators. This action has severely impacted the only known subpopulation of Shasta crayfish on the Pit River. All fish hatchery operations have been suspended pending further evaluation of the compatibility of fish hatchery activities and the maintenance of a healthy Shasta crayfish population.

Hat Creek. Downstream movement of sediment from the Hat Creek Mudflow of 1915, greatly accelerated when the Army Corps of Engineers channelized Hat Creek in the 1950's (L. Kerns, pers. comm. 1994), continues to impact Shasta crayfish habitat. Shasta crayfish populations have been documented in the spring-fed lakes and rivers feeding into lower Hat Creek, but not in mainstem Hat Creek itself since the mudflow. Habitat and hydrology have been impacted by the construction and operation Hat Creek 1 and 2 Hydroelectric Project.

Several trout management and restoration techniques applied to the Hat Creek drainage since the 1940's were done without knowledge of either the presence of or the potential impacts on Shasta crayfish. Rotenone and liquid chlorine have

been added to Crystal Lake in an attempt to eradicate the protozoan *Ceratomyxa* (Schafer 1968, M. Berry, pers. comm. 1995). Pro-noxfish or rotenone has also been used to remove nongame fish as part of the wild trout program on Hat Creek. A toxicant such as rotenone is equally as toxic to invertebrates, such as crayfish, as it is to fish.

To create additional spawning habitat for trout, river gravel was added to the outflow area of Crystal Lake using heavy machinery in 1965 and 1971. The lava cobbles and boulders that define Shasta crayfish habitat were buried, and no Shasta crayfish were found in the new gravel areas in the river. In 1993, Ellis (pers. observ.) estimated that the current size of the Shasta crayfish subpopulation at the outflow of Crystal Lake was less than 10 percent of the 2,000–3,000 individuals estimated in 1978 (Daniels 1978).

Crystal and Baum lakes receive considerable fishing pressure, including crayfishing, and other disturbances from public use. According to Eng (unpubl. notes), these crayfish are particularly vulnerable to hand collecting. Bullfrogs and brown bullhead have been introduced to the lakes. Grazing, logging, and other disturbances have contributed to surface runoff, sedimentation, and eutrophication of the lakes. The lack of exclusion fencing allows cattle to graze in the riparian zone and wade into the lakes. There is evidence of bank erosion and loss in parts of both lakes. Invasions and interactions with signal crayfish are the principal current threats.

Rising River. Aerial photographs from 1957, 1964, 1973, and 1993 all show a white plume of fine sediment issuing from the springs in the middle arm at the west end of the headwater spring system (not Rising River Lake) and some in the headwater spring closest to the middle arm, but none coming from any of the other headwater springs. There have been no studies of sediment in Rising River upstream of Hat Creek, so the ultimate source of this sediment and the flow rates into and downstream are unknown. There is some anecdotal evidence indicating that fine sediment in Rising River has increased in recent times.

Rising River and Rising River Lake were once the location of several working ranches. Although there are still livestock in areas, there is no grazing in the riparian zone. There is little evidence of bank erosion. In general, this area has been relatively undisturbed. Native beaver and introduced muskrats are both common.

The Rising River Shasta crayfish populations are currently free of signal crayfish. The potential invasion by signal crayfish is the principal current threat.

H. Conservation Measures

Regulatory Measures

The Shasta crayfish was listed as an endangered species by the California State Fish and Game Commission in 1988, thus offering protection from take, possession, or sale within the State of California. Other State regulations prohibit the take, possession or use for bait of any crayfish species within the range of the Shasta crayfish. These regulations were enacted to protect the Shasta crayfish and prevent the accidental spread of exotic crayfish. However, the large size and remoteness of the area make enforcement difficult.

In an attempt to protect Shasta crayfish, the midsections of the Pit River have been closed to crayfishing and the use of crayfish as bait since 1981. Some areas are now open for crayfishing where the introduced species are abundant (e.g., the Fall River downstream of the confluence of Tule River, including Pit I Forebay, Fall River Pond, and Lake Britton), but the restriction on the use of crayfish as bait remains.

The Shasta crayfish was federally listed as an endangered species on September 30, 1988 (U.S. Fish and Wildlife Service 1988) . Federal agencies are required to consult with the Service under the provisions of section 7(a)(2) of the Endangered

Species Act (Act) on any action that they fund, permit, or implement that may affect Shasta crayfish. The provisions of Section 9 also makes it illegal to ship, sell or offer for sale in interstate or foreign commerce any listed species, or part thereof, taken in violation of the Act. The Service also enforces the provisions of section 9 of the Act, which makes it illegal to harass, harm, pursue, hunt, shoot, wound, trap, capture, collect, or to attempt to engage in any such conduct. If a non-federal action would result in the take Shasta crayfish, an incidental take permit, issued by the Service under section 10(a)(1)(b) of the Act would be required. Section 6 funding is provided to states for actions that will aid the recovery of listed species.

There are no previous formal consultations on file for the Shasta crayfish since 1988 when it was listed. There will be a formal consultation resulting from the relicensing of PG&E's Pit I hydroelectric development on the Pit River in 1997-1998. During the relicensing process PG&E will be addressing improvement of land use practices and protection zones around lakes for Hat Creek.

The California Water Resources Control Board issues both waste discharge permits for liquid waste discharges and 401 Water Quality Certifications for discharges to navigable waters, which require a federal permit or license.

California Department of Fish and Game issues Stream and Lake Alteration Agreements under Sections 1600-1605 of the California Fish and Game Code for the alteration of any stream or water course depicted as a blue-line channel on United States Geological Survey (U.S.G.S.) topographic maps.

Bear Creek Restoration

A cooperative effort has been mounted between the property owners in Bear Creek meadow and the managers of the timber lands upstream to reduce and stabilize the sediment flux into Fall River from Bear Creek. Such measures have

included exclusion of cattle from riparian areas and replanting of native willows adjacent to the creek. Studies on Bear Creek determined that the current primary sediment source is the degraded channel in the meadow, rather than the upper watershed. A plan is being developed to stabilize the channel through the meadow (L. Leopold and D. Rosgen, pers. comm. 1994; R. Poore, pers. comm. 1996). This plan is currently being developed to meet three primary objectives: (1) to connect the channel with the floodplain, (2) to eliminate the meadow section as a major sediment source, and (3) to maintain the channel through the meadow. A permit application package is being developed at this time but is not yet completed.

The Natural Resources Conservation Service (NRCS) is conducting an inventory of potential sediment and erosion sources in the Bear Creek watershed during 1997.

Levee Management

PG&E began fencing the levees surrounding McArthur Swamp in Fall 1991. By the end of 1992, exclusion fences surrounded all of McArthur swamp except for the Wildlife Habitat Improvement Area (WHIP). Fencing in the WHIP was completed in the Fall of 1995 (M. Drury, pers. comm. 1996). PG&E will be addressing habitat enhancement and alternatives to dredging in their application for a section 404 permit from the Army Corps of Engineers for their long-term levee maintenance along the Upper Tule River.

Grazing cattle on McArthur Swamp are now excluded from all of the PG&E levees, Big Lake, and the Tule River. This will reduce the need for levee maintenance, improve bank condition and riparian vegetation, and help stop the degradation of existing Shasta crayfish habitat.

Although PG&E still uses dredging as the primary method of levee maintenance and repair, they constructed a road on the levee west of Rat Farm and imported material with lava cobbles and boulders to repair a major levee breach resulting from the January 1, 1997 high-water event. Importing material to areas within the known distribution of Shasta crayfish creates new potential Shasta crayfish habitat.

Maria Ellis is addressing the issue of monitoring non-agency dredging by attending public meetings and coordinating with The Fall River Resource Conservation District.

Pit River Fish Hatchery

Signal crayfish invaded the Sucker Springs Creek subpopulation of the Shasta crayfish when barriers between Ponds 3, 4, and 5 were removed for approximately one month in August 1996. All fish hatchery operations and activities were suspended pending further evaluation of the compatibility of fish hatchery activities with maintaining a healthy Shasta crayfish population. CDFG has been conducting surveys and eradication of signal crayfish in Pond 3. CDFG and the Fish and Wildlife Service will be working together to develop an appropriate management plan for the future.

Current coordination with landowners

Between 1990 and 1995 coordination between Maria Ellis and private landowners was initiated to develop partnerships for managing the Shasta crayfish. These efforts included: establishing communication, gaining permission to access properties to conduct surveys, and public education.

Research

Shasta crayfish. Between 1990 and 1995 three projects were initiated to study and/or manage Shasta crayfish, supported by CDFG in part by Federal funds under provisions of section 6 of the Endangered Species Act. These projects included: Ecology and Competition Studies, Competitor Control and Habitat Improvement, and Disease and Fungus Control Studies.

Considerable thought and research has gone into a design for velocity barriers to prevent nonnative crayfish from invading populations of Shasta crayfish (Ellis 1994b). Although the design is experimental, an overhanging velocity and/or physical barrier constructed from bank to bank and extended between 0.31–0.46 meter (1–1.5 feet) above the substrate, depending on current, would prevent the upstream migration of crayfish, while allowing the passage of fish (Figure 7). In low or no current areas, the height of the barrier would have to be increased since it would be functioning solely as a physical barrier. Field tests for crayfish barriers were included as part of the section 6 funded projects in 1994. However, these plans were changed and restoration plans were developed in lieu of the field tests. No field testing of crayfish barriers has been conducted to date and is a Priority 1 task in this recovery plan.

Geothermal Development and Recharge Area Research. Concerns have been raised regarding the geothermal development of the Medicine Lake Highlands area before adequate research has been conducted (Dr. T.L.T. Grose, and M.J. Ellis *in litt.)*. A research proposal by the Lawrence Livermore National Laboratory and the Department of Geology, Colorado School of Mines (Davisson *et al.* 1997) would provide necessary information to determine whether geothermal development of the Medicine Lake Highlands would impact springs of the Fall River and Shasta crayfish that live there. This research should be conducted prior to any further exploration or development of the Medicine Lake Highlands.

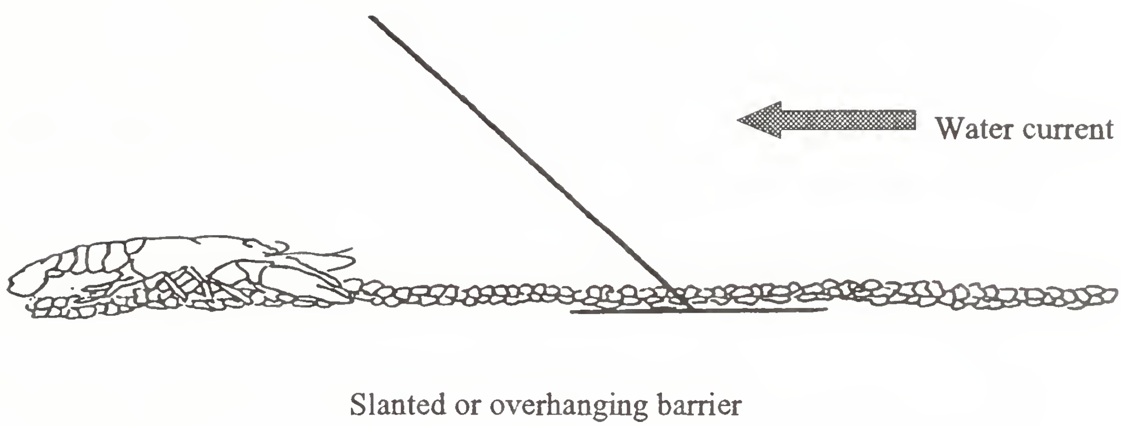


Figure 7. An example of a physical/velocity barrier to the upstream migration of crayfish.

Similar research conducted in the Hat Creek basin in 1993 ultimately showed that the proposed transfer of Lost Creek water to Hat Creek at Bidwell Ranch would have decreased the discharge of the springs in Rising River almost immediately (Rose 1994, Rose *et al.* 1996). If implemented, this transfer project would have resulted in a permanent decrease in the discharge of the Rising River springs of greater than 20 percent. This would likely have had a negative impact on the Rising River Shasta crayfish population.

Spring Creek

In November 1996, CDFG began working with Shasta County to excavate material from the downstream end of the culverts under Spring Creek. These culverts act as velocity barriers to signal crayfish. CDFG has also conducted two surveys since then to monitor the status and condition of the culverts and to survey for signal crayfish upstream from the culverts.

Upper Fall River

Habitat enhancement has been initiated in this area during the course of surveys for Shasta crayfish. Lava rocks covered with sediment are turned over and laid on top of sediment exposing interstitial spaces important to Shasta crayfish. This type of enhancement needs to continue on a regular basis

The Fall River Resource Conservation District (FR RCD) is currently directing a $200,000 watershed study that will consider the use of limited dredging, natural flushing, and restoration of the river morphology to mimic historic sediment transport conditions (Poore 1995)

I. Consideration of Proposed and Candidate Species and Species of Concern

The following special status species may occur within Shasta crayfish habitat and could potentially be impacted by recovery actions for the Shasta crayfish: the rough sculpin (State threatened and Federal species of concern), the California floater (a mussel) and Montane peaclam (Federal species of concern), the northwestern pond turtle (Federal species of concern), and the bald eagle (Federal threatened, State endangered). Actions recommended in this recovery plan that could benefit other rare endemics in the area include: improving water quality in the Pit River drainage, reducing nonnative species, improving land management practices, and increasing public awareness regarding listed species. Some actions are expected to have negligible negative effects on special status species in the area.

Increasing the flow of water from the Fall River to the Pit River below the diversion dam would improve water quality for aquatic species in that section of the Fall River and the Pit River. A secondary benefit would be improved prey populations for species feeding on aquatic life (e.g. the bald eagle). The building of crayfish barriers could create temporary disturbance to species and habitats in the area of construction. Enhancing habitat by adding lava cobble and boulders could impact mussel habitat and disturb and/or take individuals. The impact is expected to be negligible because the habitat enhancement will be taking place along the levees where only a small percentage of mussels are found.

Recovery actions that protect riparian habitat and promote native plants on levees could enhance or protect habitat for terrestrial species in the area. Appendix C lists terrestrial vertebrate and plant species with special status that may occur in proximity to Shasta crayfish habitat but are highly unlikely to be impacted by recovery actions for the Shasta crayfish.

J. Recovery Strategy

The invasion of nonnative crayfish species, in particular signal crayfish, is the single largest threat to the continued existence of Shasta crayfish. The continued existence of Shasta crayfish would be ensured when the subpopulations of the seven remaining populations are protected from the invasion of nonnative species, particularly the signal crayfish, and from other disturbances. Spring Creek and Rising River are the only two populations where **all** subpopulations are free of nonnative crayfish (Table 4). All of the Hat Creek and Pit River subpopulations have been invaded by nonnative crayfish. The remaining three populations (Upper Fall River, Lava Creek and Upper Tule River) have some invaded and some pure Shasta crayfish subpopulations (Table 4).

When all of the subpopulations that are currently free of signal crayfish are protected and considered stable (defined as self-sustaining populations comprising representatives of all age classes), Shasta crayfish could then be reclassified as threatened. Recovery actions would then be focused on subpopulations that have been invaded by nonnative crayfish species. When signal crayfish are eradicated or controlled and these subpopulations are also protected from other disturbances so that these Shasta crayfish subpopulations are also considered stable, Shasta crayfish can be considered recovered and delisted.

The primary goal is to protect and stabilize the currently known Shasta crayfish subpopulation. This protection will maintain the genetic diversity of the species. Many tasks are primarily aimed at subpopulations that are currently free of nonnative crayfish, as well as a few select invaded subpopulations, and include designing, testing, and installing efficient crayfish barriers and maintaining some present barriers (i.e., culverts and weirs) useful in preventing signal crayfish invasions. Other site-specific tasks include habitat restoration and enhancement, working with landowners, improving land use practices, eradicating signal crayfish, stabilizing river and stream banks with plantings, developing dredging alternatives, eliminating fish hatchery operations, and fishing restrictions.

Table 4. Summary of the status of all known subpopulations within the eight geographically isolated populations of Shasta crayfish.

Populations	Subpopulations [1]											
	Invaded by Nonnative Crayfish					Pure Shasta Crayfish					Total Existing	Total Extinct
	S/D	S	D	NS	**Total**	S/D	S	D	NS	**Total**		
Upper Fall River	1	1	2	1	**5**		3			**3**	8	
Lava Creek			2		**2**		2			**2**	4	1
Upper Tule River	1		3		**4**	3	6			**9**	13	
Pit River	2		2		**4**						4	1?
Hat Creek			3	1	**4**						4	
Spring Creek							2			**2**	2	
Rising River							3	1		**4**	4	
Fall River Mills (extinct)												1
TOTAL	**4**	**1**	**10**	**2**	**= 17**	**3**	**16**	**3**		**= 22**	**39**	**3**

[1] S/D = stable or declining?, S = stable, D = declining, NS = not self-sustaining population (probably incidental sighting), ? = presumed

Other tasks are directed at subpopulations of Shasta crayfish that already have signal crayfish. These tasks include stabilization of populations, eradication programs for signal crayfish, and habitat enhancement. Some of the suggested methods for achieving these goals are experimental, such as the design, construction, implementation, and maintenance of crayfish barriers. A field test of a crayfish barrier design followed by a one-year monitoring/maintenance period during which different eradication methods can be employed upstream from the barrier will provide valuable information for future plans. The methods/techniques for the control and/or eradication of nonnative crayfish are also somewhat experimental and the likelihood of success is unknown. The probability of complete eradication of signal crayfish from large areas is low.

Another goal is to determine the distribution, status, and relative abundance of Shasta crayfish in the mainstem Pit River. Because the environment in the mainstem Pit River is much more variable than in other Shasta crayfish locations, this study should also examine the potential impacts of variations in discharge (e.g., habitat availability, flow velocity, and substrate stability), water quality, and temperature on the Pit River Shasta crayfish population.

Additional research is needed on the ecology and requirements of Shasta crayfish, the dynamics of Shasta crayfish behavior and interspecific interactions with invading species (signal crayfish and fantail crayfish), and the importance and impact of signal crayfish and fantail crayfish pathology on Shasta crayfish. This information is integral for the recovery and management of Shasta crayfish to maintain self-sustaining populations having representatives of all age classes.

II. RECOVERY

A. Objectives and Criteria

The primary objective of this plan is to stabilize and protect existing populations so that Shasta crayfish may be reclassified as a threatened species and ultimately delisted.

Criteria for Downlisting:

1. The major subpopulations within five Shasta crayfish populations that are currently free of nonnative crayfish species (i.e., upper Fall River, Spring Creek, upper Lava Creek, upper Tule River, Rising River) are protected to ensure they remain isolated from nonnative crayfish species, especially signal crayfish.

2. The Crystal Lake population and the Sucker Springs Creek subpopulation (Pit River population) are protected and stabilized by eliminating, reducing, or managing signal crayfish.

3. Signal crayfish are eradicated in lower Lava Creek, so that Shasta crayfish are once again free of signal crayfish throughout the entire Lava Creek subdrainage.

4. The major subpopulations of the five populations that are free of nonnative crayfish and the Crystal Lake and Sucker Springs Creek populations are stable (i.e., self-sustaining and comprising representatives of all age classes) with population sizes that are stable (e.g., upper Fall River, Spring Creek, and Rising River Lake outflow channel) or increasing (e.g., Lava Creek, upper Tule River, Crystal Lake, and Sucker Springs Creek) over a 5-year period.

5. The major subpopulations in each of the seven Shasta crayfish populations are protected from disturbances related to land use practices.

Criteria for Recovery:

1. Nonnative species, in particular signal crayfish, have been eliminated, reduced, or managed in all Shasta crayfish subpopulations, so that they no longer threaten the continued existence of Shasta crayfish at these sites.

2. All Shasta crayfish subpopulations are stable (i.e., self-sustaining and comprising representatives of all age classes) with population sizes that are increasing over a 5-year period.

B. Narrative Outline for Recovery Actions

1. Protect the remaining populations of Shasta crayfish currently free of nonnative crayfish.

   Of the seven Shasta crayfish populations, five either have no nonnative crayfish species or have major subpopulations that have no nonnative crayfish (Table 4). Protecting Shasta crayfish populations from signal crayfish invasions and other disturbances and ensuring their stability are the first priorities for recovery of Shasta crayfish. Two subpopulations, which have already been invaded by signal crayfish, are included in this section because the recovery tasks are the same as for populations that are currently free of signal crayfish.

   1.1 Protect the Upper Fall River Population—currently free of signal crayfish.

   The Thousand Springs fish trap cove and old property line, Fall River

sand springs, and Rainbow Spring are still free of signal crayfish and represent the major subpopulations of the upper Fall River population and one of the larger populations of Shasta crayfish. Thousand Springs is considered the most pristine location where Shasta crayfish are found. Protection of this population is essential to the recovery effort.

1.1.1 <u>Secure the cooperation of landowners to manage and protect Shasta crayfish</u>.

The Thousand Springs and Rainbow Spring properties are privately-owned and closed to the general public. The cooperation of both of these landowners is necessary to implement recovery actions relating to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish. A cooperative agreement should be developed with the landowners to implement recovery actions related to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish.

1.1.2 <u>Install a crayfish barrier upstream of the Navigation Limit</u>.

Construction of a physical/velocity barrier to stop the upstream advancement of signal crayfish is necessary to maintain and protect this major subpopulation of the upper Fall River population. A flume study (task 3.1) must be conducted prior to barrier installation.

1.1.3 <u>Restore Bear Creek meadow</u>.

Bear Creek meadow should be restored so that it ceases to be a net source of sediment into the Fall River. Restoration of Bear Creek meadow is essential to the recovery of Shasta crayfish,

because Bear Creek sediment is a continuing threat to Shasta crayfish populations in the Fall River.

1.1.4 Enhance Shasta crayfish habitat upstream of the Navigation Limit.

All visible lava cobbles and boulders should be uncovered by turning the rocks over so that they are on top of the gravel, instead of covered by gravel. This can be accomplished by divers during monitoring surveys. If there is still a shortage after uncovering larger substrate, appropriate substrate can be imported by hand from the surrounding area. Appropriate substrate consists of large (at least 25.4 cm [10 inches] diameter) lava cobbles and boulders (approximately two to three large cobbles/small boulders per square meter [approximately one per square foot]), generally on top of lava gravel. Emphasis should be placed on the area between Rainbow Spring outflow and the Navigation Limit.

1.2 Protect the Spring Creek Population—free of signal crayfish.

This population is entirely free of nonnative crayfish and protecting it is essential to the recovery effort.

1.2.1 Secure the cooperation of landowners to manage and protect Shasta crayfish.

The Spring Creek property is privately-owned and closed to the general public. The cooperation of this landowner is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat. The cooperation of the

downstream landowner is necessary to fortify the upstream migration barrier for the exclusion of nonnative crayfish. A cooperative agreement should be developed with the landowners to protect and manage Shasta crayfish in Spring Creek.

1.2.2 Examine the barrier created by the four culverts at Spring Creek Road crossing and fortify if necessary.

Examine the four culverts at Spring Creek Road crossing to determine if they are adequate physical/velocity barriers to the upstream migration of signal crayfish and fortify if necessary. The possibility that signal crayfish could move overland across Spring Creek Road should also be considered and, if necessary, steps should be taken to prevent such movement.

1.2.3 Enhance Shasta crayfish habitat in lower fish trap cove.

Although there is ample, clean lava gravel in lower fish trap cove, there is a shortage of lava cobble and boulders. Appropriate substrate from the surrounding area should be placed in lower fish trap cove to enhance Shasta crayfish habitat. Because only a small amount of lava substrate would be necessary to enhance this relatively small area, lava substrate can be placed by hand so that the disturbance to Shasta crayfish is minimal.

1.3 Protect the Lava Creek Population—some subpopulations have signal crayfish.

The Shasta crayfish subpopulations in the headwaters of the east and west arms of Lava Creek are still believed to be free of signal crayfish. Protection of these subpopulations from invading signal crayfish is essential to the recovery effort. Signal crayfish have invaded Lava Creek from the confluence of its east and west arms to the Tule River. Lava Creek has the largest nearly continuous expanse of Shasta crayfish habitat of any location. The return of this entire stream to a Shasta crayfish population free of signal crayfish would provide a valuable refuge for the species.

1.3.1 Secure the cooperation of landowners to manage and protect Shasta crayfish.

There are several private properties along Lava Creek. One of these properties is a fly-fishing club. Lava Creek is closed to the general public. The cooperation of these landowners is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish. A cooperative agreement should be developed with these landowners to protect and manage Shasta crayfish on their properties.

1.3.2 Install crayfish barriers in both the east and west arms of Lava Creek.

A physical/velocity barrier should be constructed in both the east and west arms of Lava Creek upstream of the invasion front of signal crayfish. This barrier would stop the continued

upstream advancement of signal crayfish into the headwaters. A flume study (task 3.1) must be conducted prior to barrier installation.

1.3.3 Install a crayfish barrier at the outflow of Lava Creek.

Install a crayfish barrier at the outflow of Lava Creek into the Tule River and in the small drainage ditch on the west side to stop the invasion of signal crayfish from Eastman Lake. This barrier would minimize or reduce the source population of signal crayfish that could migrate into the headwaters of Lava Creek and be a first step towards securing Lava Creek as a population free of signal crayfish. A flume study (task 3.1) must be conducted prior to barrier installation.

1.3.4 Initiate a signal crayfish eradication program in Lava Creek.

Use baited traps and hand collecting to eradicate signal crayfish in Lava Creek. The control and/or eradication of signal crayfish will require repeated efforts, potentially over a period of years, to be successful. Trained people, preferably on-site land managers or owners of the property, should set multiple baited traps year round to trap as many signal crayfish as possible. Concurrent with the trapping effort, repeated surveys should be conducted by multiple divers to hand collect signal crayfish. The status of Shasta crayfish in the area can be monitored during these surveys, as well (task 4.2). If it is determined that signal crayfish have been eradicated from Lava Creek (task 4.1), and that there are no potential pathogens, parasites, or commensals carried by the Shasta crayfish (tasks 3.2.2.3 and 3.2.2.4) that coexisted with signal crayfish, then the upstream barriers in the east and west arms can be removed.

1.4 Protect the Upper Tule River Population—free of signal crayfish.

Eight subpopulations of Shasta crayfish in the upper Tule River are probably still free of signal crayfish: the six Big Lake subpopulations, the Ja-She Creek headwaters subpopulation, and the Crystal Springs, Cove and Inlet subpopulation. Protection of the Big Lake and Ja-She Creek headwater subpopulations is essential to the recovery effort. (Crystal Cove is so large that installing barriers is probably not realistic.)

1.4.1 Secure the cooperation of PG&E and the CDPR to manage and protect Shasta crayfish.

PG&E owns most of the land, river and lakebeds, and water rights in the upper Tule River subdrainage. PG&E also maintains the levee system where a number of Shasta crayfish subpopulations are found. The CDPR owns the property (i.e., Ahjumawi Lava Springs State Park) along the northern part of the subdrainage and the streambed of Ja-She Creek upstream of the state park road crossing (Ja-She Creek bridge). The cooperation of PG&E and CDPR is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat and the exclusion of nonnative crayfish. A cooperative agreement should be developed with PG&E and CDPR to protect and manage Shasta crayfish on their property (this task also contributes to recovery goals for populations already invaded by signal crayfish in the Upper Tule River population).

1.4.2 Assess and install a crayfish barrier for the outflow of Big Lake into the Tule River at Rat Farm.

The constriction where Big Lake flows into the Tule River at Rat Farm is the only likely location where a physical upstream migration barrier could be built. Installation of a barrier at this location, which was upstream of the invasion front of signal crayfish at the time of the last survey, would prevent signal crayfish from invading Big Lake. A flume study (task 3.1) must be conducted prior to barrier installation. If feasible, install the barrier.

1.4.3 Install a crayfish barrier at Ja-She Creek bridge on Ja-She Creek.

The construction of a physical/velocity barrier where Ja-She Creek flows under the Ahjumawi Lava Springs State Park road at Ja-She Creek bridge would prevent signal crayfish from invading Ja-She Creek. A flume study (task 3.1) must be conducted prior to barrier installation.

1.4.4 Assess and develop a crayfish barrier for Crystal Cove and Crystal Inlet.

1.4.4.1 Assess feasibility of installing a crayfish barrier at Crystal Cove and Crystal Inlet.

Because the cove is fairly wide it may not be feasible to build a barrier across it. The opening to Crystal Inlet is narrow enough, but the Crystal Inlet

subpopulation of Shasta crayfish probably represents less than half of the total Crystal Cove population. The construction of a physical upstream migration barrier across Crystal Cove would prevent signal crayfish from invading both Crystal Cove and Crystal Inlet and protect the only subpopulation free of signal crayfish in lower Ja-She Creek. A flume study (task 3.1) must be conducted prior to barrier installation.

1.4.4.2 Install barrier at Crystal Cove.

If task 1.4.4.1 determines that it is feasible, install the barrier at Crystal Cove.

1.4.5 Initiate a signal crayfish eradication program upstream of all barriers.

Use baited traps and hand collecting to eradicate signal crayfish upstream of the barriers in the upper Tule River. This would eliminate any nonnative crayfish in Big Lake, Ja-She Creek headwaters, and Crystal Cove.

1.4.6 Develop alternative levee maintenance practices.

Dredging should be replaced by reconstruction of the levees using material trucked in from borrow pits. The material from borrow pits would be more structurally sound than dredged material. Use of lava substrate would fortify the levees and create additional habitat for Shasta crayfish. An action plan must be developed prior to any lava placement to minimize the disturbance and impact on Shasta crayfish. To minimize

disturbance, Shasta crayfish could be temporarily relocated to habitat nearby and replaced after the levees are fortified. (If there is no adjacent habitat, substrate could be added to create a suitable relocation area.)

1.4.7 Enhance and create Shasta crayfish habitat.

Enhance Shasta crayfish habitat in all subpopulations in Big Lake and the Horr Pond levee except North Big Lake and Big Lake Spring populations. Add appropriate substrate. An action plan must be developed prior to any lava placement to minimize the disturbance and impact on Shasta crayfish. Shasta crayfish could be temporarily relocated to habitat nearby and replaced after the habitat enhancement. (If there is no adjacent habitat, substrate could be added to create a suitable relocation area).

1.4.8 Plant levees and riparian areas with native plants.

Plant levees and riparian areas with perennial grasses and other native species (such as willows) to aid in bank stabilization. This would reduce the need for levee maintenance, increase bank stability, reduce sediment input, and result in less disturbance to Shasta crayfish populations in the vicinity of the levees and streambanks. Burn the existing vegetation on the levee before seeding (this task also contributes to recovery goals for populations already invaded by signal crayfish in the area).

1.5 Protect the Rising River Population—free of signal crayfish.

The Rising River subdrainage, including Rising River, Rising River Lake, and the Rising River Lake outflow channel, contains the only

Shasta crayfish population free of signal crayfish in the Hat Creek drainage. Protection of this population is essential to the recovery effort.

1.5.1 <u>Secure the cooperation of landowners to manage and protect Shasta crayfish</u>.

There are four private properties on the Rising River subdrainage. Rising River is closed to the general public. Shasta crayfish are located on the two upstream properties. The cooperation of both of the upstream landowners is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat. The cooperation of the landowner upstream of the Cassel bridge is necessary to implement recovery actions related to exclusion of nonnative crayfish. A cooperative agreement should be developed with these landowners to protect and manage Shasta crayfish on their properties.

1.5.2 <u>Install a crayfish barrier on Rising River at the Cassel Road crossing</u>.

The construction of a physical/velocity upstream migration barrier where Cassel Road crosses Rising River (1.9 miles upstream of the town of Cassel) would prevent signal crayfish from invading the majority of the Rising River subdrainage. This upstream migration barrier would protect all Rising River subpopulations of Shasta crayfish and a large expanse of suitable habitat that is not being used by Shasta crayfish, but probably would be suitable as refugia. A flume study (task 3.1) must be conducted prior to barrier installation.

1.6 Protect the Pit River subpopulations at Sucker Springs Creek—invaded by signal crayfish.

The largest concentration of Shasta crayfish in the midsections of the Pit River, one that was once free of signal crayfish, is located at Sucker Springs Creek in Pond 3 of the CDFG Pit River Hatchery. As a result of the 1996 invasion of signal crayfish into Pond 3 at the CDFG Pit River Hatchery, this subpopulation is no longer free of signal crayfish, and its numbers have been dramatically reduced (Ellis 1997). The eradication of signal crayfish and the restoration and protection of the Sucker Springs Creek subpopulation are essential to recovery of the Shasta crayfish.

1.6.1 Secure the cooperation of PG&E and CDFG to manage and protect Shasta crayfish.

The cooperation of PG&E, as the landowner, and CDFG, the lessee (Pit River Hatchery), is necessary to implement recovery actions related to management of Shasta crayfish and their habitat and exclusion of nonnative crayfish.

1.6.2 Discontinue fish hatchery management activities that threaten the Sucker Springs Creek Shasta crayfish population.

Basic hatchery management activities (repeated electroshocking of the ponds, substrate removals, use of heavy machinery in areas where Shasta crayfish are/were found, removal of weirs that act as barriers to the upstream migration of signal crayfish, and use of salt, copper sulfate, and other chemicals) threaten the Shasta crayfish population in Sucker Springs Creek and should be discontinued.

1.6.3 Ensure that the weirs between all ponds (Ponds 1,2,3,4, and 5) and downstream of Pond 5 are kept in place.

These weirs act as barriers to the upstream migration of signal crayfish. Ensuring that all of these weirs (including the flashboards) are kept in place will prevent further upstream migration of signal crayfish into the Shasta crayfish population in Sucker Springs Creek.

1.6.4 Restore habitat in Ponds 1 and 2 and relocate Shasta crayfish from Ponds 2 and 3.

Eradication of signal crayfish in Pond 3 will result in substantial habitat disturbance and potential impacts to individual Shasta crayfish. Restoring habitat in Ponds 1 and 2 will create refugia to relocate Shasta crayfish to during eradication and restoration procedures in Pond 3. Restoration in Ponds 1 and 2 will also create additional habitat in Sucker Springs Creek.

1.6.4.1 Restore Shasta crayfish habitat in Ponds 1 and 2.

Remove the fencing/revetment along the north banks of Ponds 1 and 2 and rearrange/import lava cobbles and boulders along the northern third of these ponds.

1.6.4.2 Remove any Shasta crayfish found in Pond 2 to Pond 1.

During task 1.6.4.1, there is the remote possibility of finding some Shasta crayfish behind the fencing/revetment in Pond 2 that were not detected

previously. If any Shasta crayfish are found in Pond 2 and NO SIGNAL CRAYFISH are found, move these Shasta crayfish to Pond 1. (This step is necessary to avoid contaminating any Shasta crayfish in Pond 2 that have never been exposed to signal crayfish disease and/or commensals). The weir between Ponds 1 and 2 should be maintained.

1.6.4.3 Relocate Shasta crayfish from Pond 3 to Pond 2

Once Pond 2 is restored and any Shasta crayfish relocated to Pond 1, all Shasta crayfish in Pond 3 should be relocated to Pond 2.

1.6.5 Initiate a signal crayfish eradication program in Ponds 3 and 4.

Once task 1.6.4.3. is completed, initiate an eradication program in Ponds 3 and 4 using baited traps and hand removal. Eradication will be considered complete if signal crayfish are not found during complete surveys for 3–4 consecutive years.

1.6.6 Restore habitat in Pond 3

Enhance crayfish habitat in Pond 3 by relocating appropriate substrate by hand from the banks and hillside into the channel. Import additional lava rock if necessary.

1.6.7 Install a crayfish barrier at the mouth of Sucker Springs Creek.

Install a crayfish barrier at the mouth of Sucker Springs Creek to prevent further invasion of signal crayfish from the Pit River. A

flume study (task 3.1) must be conducted prior to barrier installation.

1.6.8 Initiate a signal crayfish eradication program in Sucker Springs Creek.

Implement a program to eradicate signal crayfish in Sucker Springs Creek, downstream of Pond 3, using baited traps and hand collection.

1.6.9 Remove all barriers between Ponds 3, 2, and 1

When eradication of signal crayfish (task 1.6.5) and habitat enhancement complete (tasks 1.6.4.1 and 1.6.6) in Pond 3 are complete, and a barrier is constructed at the mouth of Sucker Springs Creek (task 1.6.5), remove barriers between Ponds 3, 2, and 1 and allow crayfish to colonize all available habitat.

1.7 Restore Sucker Springs Creek at the Pit River Hatchery.

Restoration of habitat at the hatchery at Sucker Springs Creek would provide a refuge for Shasta crayfish. Experiments in semicaptive rearing and breeding of Shasta crayfish could potentially be conducted in Sucker Springs Creek, to increase the natural production of the species at this location.

1.7.1 Restore streambanks to natural conditions in the area of Sucker Springs Creek impacted by the Pit River Hatchery.

All cement walls, walkways, and revetments should be removed and the streambanks restored to natural conditions. This would

require the use of heavy machinery for the reconstruction of the south bank, but would not require heavy machinery use in the channel.

1.7.2 Add substrate.

After reconstruction to restore natural stream banks (task 1.7.1) enhance crayfish habitat by adding appropriate substrate throughout the channel by hand. In particular, lava cobbles and boulders should be placed adjacent to the existing habitat used by Shasta crayfish. Cobbles and boulders can be found along the north bank of the stream channel.

1.7.3 Evaluate the need for additional restoration activities.

Analyze characteristics of the creek channel to refine and implement any additional restoration.

1.8 Restore Sucker Springs Creek upstream of hatchery.

Sucker Springs Creek upstream of the hatchery could potentially provide habitat for Shasta crayfish if it were restored.

1.8.1 Remove the dam and culvert upstream of the hatchery.

Removal of the dam and culvert would restore normal flow in the channel upstream of the hatchery, which would flush out some of the sediment that has accumulated over the last ten years.

1.8.2 Remove sediment upstream of the hatchery, if necessary.

If removing the dam is not sufficient to wash away the sediment that has accumulated upstream of the dam, then the sediment should be removed mechanically.

1.8.3 Add substrate upstream of the hatchery, if necessary.

If there is not enough gravel in the stream channel once the sediment is removed, appropriate substrate should be imported. Lava cobbles and boulders should be placed in the stream channel upstream of the hatchery.

1.8.4 Evaluate the need for additional restoration activities.

Analyze characteristics of the creek channel to refine and implement any additional restoration.

2. Protect and enhance populations of Shasta crayfish invaded by signal crayfish.

Signal crayfish have invaded parts of five of the seven Shasta crayfish populations. Although the complete eradication of signal crayfish from all of these populations may not be feasible, the protection and enhancement of these populations is important for the recovery and management of Shasta crayfish.

2.1 Protect and enhance the Hat Creek, Cassel Population—Invaded by Signal Crayfish.

Crystal Lake has the only self-sustaining population of Shasta crayfish in the Hat Creek, Cassel population area. Signal crayfish have been in

Crystal Lake with Shasta crayfish for over seventeen years. This population may hold the answer to two major questions that are vital to the recovery effort: (1) Why did Shasta crayfish abundance decrease after signal crayfish invaded, i.e., by what mechanism (predation, competition, disease)? (2) How/why has approximately ten percent of the estimated population survived?

2.1.1 Secure the cooperation of PG&E and CDFG to manage and protect Shasta crayfish.

The cooperation of PG&E and CDFG is necessary to implement recovery actions related to the management of Shasta crayfish and their habitat and to eradicate or control nonnative crayfish. A cooperative agreement should be developed with PG&E and CDFG to protect and manage Shasta crayfish on this property.

2.1.2 Install a crayfish barrier at the outflow of Crystal Lake into Baum Lake.

Install an upstream migration barrier at the outflow of Crystal Lake to prevent the further invasion of signal crayfish from Baum Lake. A flume study (task 3.1) must be conducted prior to barrier installation.

2.1.3 Initiate a signal crayfish eradication program in Crystal Lake.

Baited traps and hand collections should be used in a signal crayfish eradication program in Crystal Lake. Installing temporary barriers would allow eradication within smaller areas.

2.1.4 Improve land use practices at Crystal and Baum lakes.

PG&E leases grazing privileges at Crystal and Baum lakes, and has contracted for salvage logging of diseased trees in the Hat Creek drainage, including Crystal Lake. These activities have contributed to surface runoff, sedimentation, and eutrophication of these lakes.

2.1.4.1 Install exclusion fencing around Crystal and Baum lakes.

Work with PG&E to install exclusion fences at Crystal and Baum lakes, to prevent cattle from grazing the riparian area and wading into the lakes.

2.1.4.2 Develop waterway protection zones around the lakes.

Work with PG&E to develop waterway protection zones around the lakes to prevent grazing, logging, or other potentially deleterious practices from occurring close to the lakes.

2.1.5 Institute fishing restrictions at the outflow of Crystal Lake.

All fishing in the outflow area of Crystal Lake downstream from the hatchery intake (i.e., the area approximately 100 meters [325 feet] upstream of the outflow) should be closed to minimize disturbance to Shasta crayfish from wading. This closure would also protect and minimize disturbance to spawning rainbow and brown trout.

2.2 Protect and enhance the Upper Tule River Population—Invaded by Signal Crayfish.

Shasta crayfish in the Tule Coves should be protected and signal crayfish should be eradicated from these areas. In addition, signal crayfish have also invaded the upper Tule River into the east- and south-shore subpopulations of Shasta crayfish. The south- and east-shore upper Tule River subpopulations would be greatly enhanced by the addition of lava substrate to create Shasta crayfish habitat. The size of the watercourse and the location of the east- and south-shore subpopulations do not lend themselves to the construction of barriers.

2.2.1 Install crayfish barriers at the entrances of east and west Tule Coves.

The construction of a physical upstream migration barrier at the entrance of east and west Tule Coves would stop the invasion of signal crayfish. A flume study (task 3.1) must be conducted prior to barrier installation.

2.2.2 Initiate a signal crayfish eradication program in Tule Coves.

Once the barriers are in place, use baited traps and hand collections to remove signal crayfish in east and west Tule Coves.

2.2.3 Enhance habitat for Shasta crayfish habitat along the upper Tule River.

Enhance Shasta crayfish habitat along the east and south shores of upper Tule River by adding appropriate lava substrate. Prior

to any lava placement, a plan must be developed to minimize disturbance and impacts to Shasta crayfish. Shasta crayfish could be temporarily relocated to habitat nearby and replaced after the levees are fortified. (If there is no adjacent habitat, substrate could be added to create a suitable relocation area).

2.2.4 Remove or control muskrat populations in the Tule River watershed.

The control and/or eradication of muskrat populations in the watershed would be beneficial to Shasta crayfish by reducing sedimentation and loss of habitat and by reducing predation. Potential control/removal programs should be explored and tested in the field.

2.3 Protect and enhance the Pit River Population in the mainstem Pit River—invaded by signal crayfish.

Recent findings of Shasta crayfish in two locations in the mainstem Pit River (Pit River Falls, Pit River Canyon Springs) renew hope that Shasta crayfish are found throughout the section of the Pit River between the historic mouth of the Fall River and the confluence with Hat Creek.

2.3.1 Secure the cooperation of PG&E to manage and protect Shasta crayfish.

PG&E owns most of the land, including the riverbed, along the midsections of the Pit River. A cooperative agreement should be developed with PG&E to protect and manage Shasta crayfish on this property.

2.3.2 Determine the status, distribution, and relative abundance of Shasta crayfish in the mainstem Pit River.

Conduct a thorough scuba/snorkel survey of at least the margins of the entire Pit River between the historic confluence of Fall River and the confluence of Hat Creek to determine the status, distribution, and relative abundance of Shasta crayfish in the mainstem Pit River. Scuba gear is necessary to conduct thorough Shasta crayfish surveys, unless water depth is less than 60 centimeters (2 feet). Because it is difficult to access the Pit River Canyon upstream of the Pit 1 Powerhouse, this section should be surveyed over an approximately 1- to 2- week period using an inflatable raft for support so that surveyors could camp overnight. The Pit River Canyon section should be surveyed when the flow in the river is low, but before it is eutrophic; depending on the season, eutrophication would probably occur in late June to July. The Pit River downstream from the Pit 1 Powerhouse can be accessed at a number of locations by dirt roads. This section should be surveyed in the mornings before Pit 1 Powerhouse increases the flow.

2.3.3 Restore a continuous release of water through the Fall River into the Pit River.

Improving water quality by releasing water continuously through the Fall River would benefit Shasta crayfish in the mainstem of the Pit River. The ideal amount of water flow needed for Shasta crayfish is unknown at this time, however, any increase of water flow in the Pit River above Pit 1 powerhouse would improve water quality and improve conditions for Shasta crayfish.

2.4 Protect and enhance the Upper Fall River Population—invaded by signal crayfish.

2.4.1 Work with agencies to include Shasta crayfish in management/restoration plans for the Fall River.

CDFG, the Central Valley Region of the RWQCB, other agencies and researchers are currently working on a study and restoration plan for the Fall River. The protection and enhancement of Shasta crayfish should be included in this plan.

2.4.2 Enhance Shasta crayfish habitat.

Uncover all visible lava cobbles and boulders at Fletcher's bend and Lennihan's footbridge by turning rocks over so that they are on top of, instead of covered by, the gravel and sediment. This enhancement can be accomplished by divers during monitoring surveys. If there is still a shortage after uncovering larger cobbles and boulders, appropriate substrate can be imported from the surrounding area.

2.4.3 Assess feasibility of installing site-exclusion barriers around Shasta crayfish habitat and install barriers if feasible.

Installation of site-exclusion barriers would protect small Shasta crayfish subpopulations and "islands" of Shasta crayfish habitat from the invasion of signal crayfish. Because Shasta crayfish do not appear to migrate far, site-exclusion barriers would have minimal impact on them. If site-exclusion barriers are mechanically feasible, install around the area of Fletcher's bend

and Lennihan's footbridge. A flume study (task 3.1) must be conducted prior to barrier installation.

2.4.4 Implement signal crayfish eradication program.

If site-exclusion crayfish barriers are installed (task 2.4.3), implement an eradication program for signal crayfish in these locations.

2.4.5 Work with private organizations to include Shasta crayfish in nonagency restoration plans for the Fall River.

The protection and enhancement of Shasta crayfish in the Fall River should be included in any plan to restore the Fall River.

2.4.6 Reintroduce or supplement Shasta crayfish populations in the Upper Fall River as necessary.

It may be possible to augment Shasta crayfish populations in the Upper Fall River after determining that threats to survival have been adequately reduced or eliminated. Task 3.3 must be completed prior to this task.

3. Conduct necessary research to develop effective management plans for the Shasta crayfish.

3.1 Design and conduct flume studies to develop and test crayfish barrier designs.

Large-scale flume studies should be designed and conducted to test the effectiveness of barrier designs using signal and fantail crayfish under

different velocity regimes, including no flow (i.e., complete physical barrier), and to determine the impacts of sedimentation and vegetation on barrier effectiveness. Studies should be completed for all site conditions before any barriers are installed within the range of the Shasta crayfish (See Appendix B).

3.2 Conduct research on the ecology, behavior, and pathology of Shasta crayfish

Management of Shasta crayfish populations requires a working knowledge of Shasta crayfish ecology, including food requirements and nutrition. Management of Shasta crayfish populations invaded by nonnative crayfish requires control of nonnative crayfish populations and determination of the major mechanisms regulating species replacement (i.e., the replacement of Shasta crayfish by signal crayfish). Determining the effects of interspecific interactions, including competition, predation, commensals, and pathology will facilitate the development and implementation of management plans for Shasta crayfish. All studies should be designed to maximize the potential benefits to the species (i.e., information that can be used to help manage and protect the species), while minimizing the impacts, disturbance, and potential mortality to Shasta crayfish.

3.2.1 Determine food preferences and nutritional requirements of Shasta crayfish.

Determine the food preferences, nutritional needs, and foraging area requirements for self-sustaining populations of Shasta crayfish. Determine the age-specific food habits throughout the range. Determine the importance of seasonally-abundant, potential food resources such as sucker, trout, and sculpin eggs.

If seasonal food resources are important to Shasta crayfish, then Shasta crayfish habitat should be redefined to include the presence of these seasonal food sources.

3.2.2 Determine the effects of signal crayfish on Shasta crayfish.

3.2.2.1 Determine the effects of signal crayfish competition and predation on Shasta crayfish.

Determine the importance and role of exploitative competition, interference competition, and predation by signal crayfish on Shasta crayfish. Determine the impacts of age, size, and aggressive dominance and other behaviors in these interactions. Current research (Ellis in prep.) will clarify the competitive effects of signal crayfish on the behavior, use of refugia, and activity level of Shasta crayfish and the impact of a two-fold size advantage of signal crayfish in these interactions. Further research is necessary to determine the effects of competitive interactions on Shasta crayfish growth and to determine if competition and predation are major mechanisms regulating species replacement.

3.2.2.2 Determine the effects of matings between Shasta crayfish and signal crayfish.

Determine the importance and role of interspecific matings between signal crayfish and Shasta crayfish and the resulting negative effects on production of

offspring (reproductive interference) by Shasta crayfish. Determine the impacts of size, gender, and behavior in these interactions. Determine if interspecific matings and reproductive interference are a major mechanism regulating species replacement.

3.2.2.3 Determine the impact of pathogens introduced to Shasta crayfish by signal crayfish.

Determine the impact of diseases, such as the crayfish plague, that may be carried by invading signal crayfish. Determine the importance and effect of fungal, protozoan, bacterial, and viral pathogens on Shasta crayfish. Determine the role that pathogens have played in the decline of Shasta crayfish populations, such as Crystal Lake.

3.2.2.4 Determine the effects of incidental secondary invaders from signal crayfish, such as commensal branchiobdellidan worms and ostracods, on Shasta crayfish.

Determine if the commensal organisms typical of signal crayfish are hosts or carriers of diseases or parasites to which Shasta crayfish are not resistant. Determine if commensal branchiobdellidan worms and ostracods have had a negative effect on Shasta crayfish and contributed to the decline of Shasta crayfish abundance in populations invaded by nonnative crayfish.

3.2.3 Determine the effects of fantail crayfish on Shasta crayfish.

Determine the importance and role of competition, predation, interspecific matings and reproductive interference by fantail crayfish on Shasta crayfish. Determine the importance and role of pathogens and commensals imported into Shasta crayfish populations by fantail crayfish. Determine the major mechanisms regulating species replacement.

3.2.3.1 Determine the effects of fantail crayfish competition and predation on Shasta crayfish.

Determine the importance and role of exploitative competition, interference competition, and predation by fantail crayfish on Shasta crayfish. Determine the impacts of age, size, and aggressive dominance and other behaviors in these interactions.

3.2.3.2 Determine the effects of interspecific matings and reproductive interference of fantail crayfish on Shasta crayfish.

Determine the importance and role of interspecific matings and reproductive interference by fantail crayfish on Shasta crayfish. Determine the impacts of size, gender, and behavior in these interactions. Determine if interspecific matings and reproductive interference are a major mechanism regulating species replacement.

3.2.3.3 <u>Determine the impact of pathogens introduced to Shasta crayfish by fantail crayfish</u>.

Determine the impact of diseases, such as the crayfish plague, that may be carried by invading fantail crayfish. Determine the importance and effect of fungal, protozoan, bacterial, and viral pathogens on Shasta crayfish. Determine the role that pathogens have played in the decline of Shasta crayfish populations, such as Crystal Lake.

3.2.3.4 <u>Determine the effects of incidental secondary invaders from fantail crayfish, such as commensal branchiobdellidan worms and ostracods, on Shasta crayfish</u>.

Determine if the commensal organisms typical of fantail crayfish are hosts or carriers of diseases or parasites to which Shasta crayfish are not resistant. Determine if commensal branchiobdellidan worms and ostracods have had a negative effect on Shasta crayfish and contributed to the decline of Shasta crayfish abundance in populations invaded by nonnative crayfish.

3.3 <u>Conduct genetic studies on Shasta crayfish subpopulations, if feasible</u>.

If genetic studies can be conducted using claws, walking legs, or other parts of Shasta crayfish that can be regenerated, then studies could determine whether subpopulations and populations have unique gene combinations so they are genetically distinct from each other.

Determining the amount of genetic diversity both within and between subpopulations would clarify the amount of movement and exchange that occurs between subpopulations.

This information would have to be obtained before any Shasta crayfish are moved, reintroduced, or added to supplement existing populations, because these activities would contaminate potentially distinct gene combinations. This genetic information will be forever obscured if Shasta crayfish from different subpopulations are combined and interbreed. In addition, if some of the small Shasta crayfish populations have already gone through severe inbreeding so that deleterious genes have been deleted, the introduction of Shasta crayfish with different genomes (sets of chromosomes) could have a negative impact on the population. Because the sacrifice of any individuals is considered to be extremely costly given the estimated size of the total Shasta crayfish population, the relative benefits of this information would have to be considered against the costs if individuals need to be sacrificed to conduct these studies.

4. Monitor and assess Shasta crayfish populations and modify management plans as necessary.

Continued monitoring of Shasta crayfish populations is necessary to determine the success of management and when recovery is achieved. Monitoring of populations upstream of barriers is necessary to ensure that these barriers are completely effective. Surveys should be ongoing to assess long-term population trends and to help identify management needs. Management plans will be revised to incorporate new information as necessary.

4.1 Periodically monitor the status of signal crayfish eradication in invaded populations.

Once eradication of signal crayfish appears to be complete, follow-up surveys of the area should be conducted to determine whether signal crayfish have been 100 percent eradicated and to determine whether crayfish barriers are successfully keeping signal crayfish from invading. The frequency of follow-up checks would be determined on a case-by-case basis based on the effectiveness of the barrier.

4.2 Monitor status of Shasta crayfish populations annually.

Monitor Shasta crayfish populations yearly to determine their status and relative abundance and to determine the presence/absence of nonnative crayfish species. (See Appendix A for monitoring methods). Monitoring would also determine whether crayfish barriers are effectively keeping out nonnative crayfish.

4.3 Monitor crayfish barriers

The integrity of crayfish barriers should be monitored several times a year. Visual inspection of barriers would be necessary immediately after major storms and runoff. Any sediment, vegetation, or debris built up on the barrier would need to be cleaned off as soon as possible.

5. Develop effective watershed and ecosystem management plans for all drainages supporting Shasta crayfish populations.

The watershed for the Shasta crayfish is defined as the midsection of the Pit River drainage, which includes the Fall River, Hat Creek, and Bear Creek subdrainages. Proper watershed management is necessary to minimize

impacts on Shasta crayfish. Watershed and ecosystem management will benefit other rare endemics, in addition to Shasta crayfish.

5.1 Work with landowners and managers to improve management practices.

A cooperative effort with landowners and managers would help protect the watershed where Shasta crayfish occur. Many landowners are already very good stewards and are practicing measures to safeguard the quality of habitat on their land. Examples still exist, however, of cattle grazing in riparian areas and along levees, which results in increased erosion and elevated sediment and nutrient loading. Other management practices need improvement including timber harvest, bridge construction, and agriculture.

5.2 Modify and enforce regulations to aid in control of nonnative species.

The control of nonnative species populations through modification and enforcement of regulations and the prevention of any introductions of new exotic species in the watershed is essential to the recovery and management of Shasta crayfish and the ecosystem.

5.2.1 Change the fishing regulations for crayfishing.

To aid in removing signal crayfish from the watershed, areas where trapping crayfish is allowed should be expanded to include: the Fall River from Spring Creek bridge to the confluence with the Pit River; in Eastman Lake and Little Tule River, exclusive of tributaries; Hat Creek from Cassel Pond to the confluence with the Pit River, exclusive of tributaries; and Lake Britton.

5.2.2 Enforce the restriction on the use of crayfish as bait.

The restriction on the use of crayfish as bait should be strongly enforced. Enforcement could be facilitated through public awareness (see task 6). In addition, potential rewards for tips or reports of violators might aid enforcement. The effectiveness of increased enforcement efforts should be evaluated and the potential for additional funding explored.

5.2.3 Prohibit the introduction of any new exotic species.

The introduction of any new exotic species, plant or animal, should be prohibited because it is almost impossible to either predict the range of impacts from introductions or to eradicate introduced species once they are established. Explore and evaluate potential methods for increased enforcement.

5.3 Establish/regulate water quality standards in the watershed in cooperation with the Central Valley Region of the RWQCB.

Good water quality is necessary for the health of the watershed and the ecosystem it supports, including Shasta crayfish.

5.3.1 Work with landowners, and managers to update irrigation systems to benefit water quality.

Update irrigation systems, particularly in the headwaters areas, to ensure that irrigation return flows can settle before they re-enter the rivers. This should limit nutrient and fine organic sediment loading.

5.3.2 <u>Explore potential effects of agricultural chemicals, including insecticides, herbicides, and fertilizers, in runoff and return flow within the drainage</u>.

In cooperation with the Central Valley Region of the RWQCB, determine the impact of agricultural chemicals, including insecticides, herbicides, and fertilizers, in runoff and return flow within the drainage. Special emphasis should be placed on conducting an updated investigation of the effects of wild rice farming on water quality. Explore ways to minimize identified impacts.

6. <u>Provide public information and education</u>.

Inform the general public about the threats to and the status of Shasta crayfish. Such a program will benefit the recovery effort and will serve to increase awareness of the causes of the species' endangerment. To counteract the perception that "the endangered crayfish is found everywhere", inform the public that there are also two introduced, non-native species of crayfish that are not federally listed living in the area. Increasing public awareness of the dangers of introduction might reduce the possibilities of introductions of other nonnatives. Increasing public awareness of the fishing regulation restricting the use of crayfish as bait in the midsections of the Pit River may help curtail bait-fishing.

6.1 <u>Post signs at the Rat Farm and Tule River boat accesses and other public use areas</u>.

Signs could be posted at the Rat Farm and Tule River boat accesses, campgrounds, and other public use areas within the range of the Shasta crayfish to inform the public about the Shasta crayfish and state the fishing regulation prohibiting the use of crayfish as bait.

6.2 Submit articles periodically in the two local papers to increase public education and awareness.

Articles about Shasta crayfish in the local and Redding newspapers would increase public awareness. Articles included in the recreation supplements in local and Redding papers are also made available to motel patrons.

6.3 Make presentations at local primary and secondary schools.

Increase the awareness of the local youth about the ecology and plight of the Shasta crayfish by giving yearly presentations. Involve school children with the recovery and management of the species.

6.4 Provide interpretive information to visitors at the Ahjumawi Lava Springs State Park.

Supply brochures and/or interpretive signs to increase public awareness about Shasta crayfish.

III. REFERENCES

Literature Cited

Abrahamsson, S.A. 1971. Density, growth and reproduction in populations of *Astacus astacus* and *Pacifastacus leniusculus* in an isolated pond. Oikos 22:373–380.

Bouchard, R.W. 1977*a*. Distribution, systematic status and ecological notes on five poorly known species of crayfishes in western North America (Decapoda: Astacidae and Cambaridae). Freshwater Crayfish 3:409–423.

Bouchard, R.W. 1977*b*. Morphology of the mandible in holarctic crayfishes (Decapoda: Astacidae and Cambaridae): ecological and phylogenetic implications. Freshwater Crayfish 3:425–452.

Bouchard, R.W. 1978. Taxonomy, distribution, and general ecology of the genera of North American crayfishes. Fisheries 3:11–19.

Brinkhurst, R.O. and S.R. Gelder. 1991. Annelida: Oligochaeta and Branchiobdellida. pp. 401–435 *in* J.H. Thorp and A.P. Covich (eds.), Ecology and classification of North American freshwater invertebrates. Academic Press, Inc. San Diego, CA.

Burt, W.H. and R.P. Grossenheider. 1976. A field guide to the mammals: North America north of Mexico. The Peterson Field Guide Series. Houghton Mifflin Company, Boston.

Butler, M.J.. IV and R.A. Stein. 1985. An analysis of the mechanisms governing species replacements in crayfish. Oecologia 66:168–177.

Crocker, D.W. and D.W. Barr. 1968. Handbook of the crayfishes of Ontario. Univ. of Toronto Press, Toronto, Ontario.

Daniels, R.A. 1974. Unpublished field notes.

Daniels, R.A. 1978. Distribution, status, and life history of *Pacifastacus fortis*. unpublished final report to United States Forest Service, 14 pp.

Daniels, R.A. 1980. Distribution and status of crayfishes in the Pit River drainage, California. Crustaceana 38:131–138.

Daniels, R.A. and P.B. Moyle. 1978. Biology, distribution and status of *Cottus asperrimus* in the Pit River drainage, northeastern California. Copeia 1978:673–679.

Davisson, M.L., T.L.T. Grose, and T.P. Rose. 1997. A combined isotope hydrology and geologic mapping approach to trace groundwater in the Medicine Lake Highlands. A pre-proposal dated January 31, 1997. 9 pp.

Dreyer, W.R. and K.L. Johnson. 1988. Archaeological investigations of stone fish traps at Ahjumawi Lava Springs State Park, Shasta County, California. unpublished report for California Department of Parks and Recreation under Interagency Agreement No. 4–100–6377, 79 pp.

Ehrlich, P.R. 1989. Attributes of invaders and the invading process: vertebrates. Pages 315–328 *in* Biological invasions: a global perspective. Edited by J.A. Drake, H.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmánek, and M. Williamson. SCOPE 37. Wiley & Sons. Ltd, Chichester.

Ellis, M.J. 1991*a*. 1991 Annual Report of the Shasta crayfish, *Pacifastacus fortis*. (Federal Fish and Wildlife Permit PRT–755945, State of California Department of Fish and Game MOU). prepared for Pacific Gas and Electric Company, Technical and Ecological Services, 3400 Crow Canyon Road, San Ramon, CA 94583. unpublished report to the United States Fish and Wildlife Service and the California Department of Fish and Game, 15 pp.

Ellis, M.J. 1991b. Asymmetrical competition and predation as mechanisms for species replacement. unpublished doctoral research proposal for the University of Michigan Department of Biology, December 13, 1991. 34 pp.

Ellis, M.J. 1993*a*. Report on the 1992 surveys of the Shasta crayfish, *Pacifastacus fortis*. (Federal Fish and Wildlife Permit PRT–755945, State of California Department of Fish and Game MOU). prepared for Pacific Gas and Electric Company, Technical and Ecological Services, 3400 Crow Canyon Road, San Ramon, CA 94583. unpublished annual report to the United States Fish and Wildlife Service and the California Department of Fish and Game, 32 pp.

Ellis, M.J. 1993*b*. Interspecific competition between Shasta crayfish and the introduced signal crayfish in the field: a removal experiment in Crystal Lake, 1992 Annual Report (Federal Fish and Wildlife Permit PRT–ELLIMJ–1, California Department of Fish and Game MOU). unpublished report to the United States Fish and Wildlife Service and the California Department of Fish and Game, 12 pp.

Ellis, M.J. 1994*a*. 1993 Annual Report for the Shasta crayfish, *Pacifastacus fortis* and rough sculpin, *Cottus asperrimus* (Federal Fish and Wildlife Permit PRT–755945, State of California Department of Fish and Game MOU). prepared for Pacific Gas & Electric Company, Technical and Ecological Services, 3400 Crow Canyon Road, San Ramon, CA 94583. unpublished report to the United States Fish and Wildlife Service and the California Department of Fish and Game, 31 pp.

Ellis, M.J. 1994*b*. Crayfish pathology and barriers, Progress report I for a management and recovery plan of the endangered Shasta crayfish, *Pacifastacus fortis*, in northeastern California. Prepared for Endangered Species Project, California Department of Fish and Game, Inland Fisheries Division, 1701 Nimbus Road, Suite C., Rancho Cordova, California 95670. unpublished report 18 pp.

Ellis, M.J. 1995. 1994 Annual Report for the Shasta crayfish, *Pacifastacus fortis* and rough sculpin, *Cottus asperrimus* (Federal Fish and Wildlife Permit PRT–755945, State of California Department of Fish and Game MOU). prepared for Pacific Gas & Electric Company, Technical and Ecological Services, 3400 Crow Canyon Road, San Ramon, CA 94583. unpublished report to the United States Fish and Wildlife Service and the California Department of Fish and Game, 21 pp.

Ellis, M.J. 1996*a*. 1995 Annual Report for the Shasta crayfish, *Pacifastacus fortis* (Federal Fish and Wildlife Permit PRT–755945, California Department of Fish and Game MOU). prepared for Pacific Gas & Electric Company, Technical and Ecological Services, 3400 Crow Canyon Road, San Ramon, CA 94583. unpublished report to the United States Fish and Wildlife Service and the California Department of Fish and Game 10 pp.

Ellis, M.J. 1996*b*. 1995 Annual Report for the recovery and management of the Shasta crayfish, *Pacifastacus fortis* (Federal Fish and Wildlife Permit PRT–755945, California Department of Fish and Game MOU). unpublished report to the United States Fish and Wildlife Service and the California Department of Fish and Game 10 pp.

Ellis, M.J. 1996*c*. Crayfish surveys and monitoring, Progress report II for a recovery and management plan of the endangered Shasta crayfish, *Pacifastacus fortis*, in northeastern California. prepared for California Department of Fish and Game, Inland Fisheries Division, Endangered Species Project, Contract No. FG3071IF. unpublished report 90 pp.

Ellis, M.J. 1996*d*. Interspecific interactions and Branchiobdellida research, Progress report IV for a recovery and management plan of the endangered Shasta crayfish, *Pacifastacus fortis*, in northeastern California. prepared for California Department of Fish and Game, Inland Fisheries Division, Endangered Species Project, Contract #FG3071IF. unpublished report 50 pp.

Ellis, M.J. 1997. Sucker Springs Monitoring Program surveys for Shasta Crayfish in Pit River Hatchery ponds 3,4, and 5, Report of Status Survey 5. Prepared for California Department of Fish and Game, Inland Fisheries Division, Endangered Species Project, Contract No. FG3071IF. unpublished report 6 pp.

Ellis, M.J. submitted. The Shasta crayfish: the making of an endangered species. Endangered Species Update, 18 pp.

Ellis, M.J. and T.F. Hesseldenz. 1993. Survey of crayfish, sculpin, and their habitat in the Fall River and midreaches of the Pit River drainage, northeastern California. prepared for: Pacific and Electric Company, Technical and Ecological Services, San Ramon, CA. 66 pp.

Eng, L.L. and R.A. Daniels. 1982. Life history, distribution, and status of *Pacifastacus fortis* (Decapoda: Astacidae). California Fish and Game 68:197–212.

Erman, D.C., T. Light, C.A. Myrick. 1993. Survey of the status of the Shasta crayfish (*Pacifastacus fortis*) in Northeastern California (1991 study year). unpublished final report for California Department of Fish and Game: September 1993, 47 pp.

Errington, P.L. 1941. Versatility in feeding and population maintenance of the muskrat. Journal of Wildlife Management 5:69-89.

Evans, N.H. 1987. Traditional Ajumawi methods of utilizing Sacramento suckers at Ahjumawi Lava Springs State Park. manuscript on file at Northeast Information Center, California State University, Chico, CA.

Faxon, W. 1914. Notes on crayfishes in the United States National Museum and the Museum of Comparative Zoology with descriptions of new species and subspecies. Harvard Museum of Comparative Zoology, Memoirs 40:352–427.

Flint, R.W. 1975. Growth in a population of the crayfish *Pacifastacus leniusculus* from a subalpine lacustrine environment. Journal of Fisheries Research Board of Canada 32:2433–2440.

Fürst, M. 1977. Introduction of *Pacifastacus leniusculus* (Dana) into Sweden: methods, results and management. Freshwater Crayfish 3:229-247.

Goldman, C.R., J.C. Rundquist, and R.W. Flint. 1975. Ecological studies of the California crayfish, *Pacifastacus leniusculus*, with emphasis on their growth from recycling waste products. Freshwater Crayfish 2:481–487.

Goodnight, C.J. 1940. The Branchiobdellidae (Oligochaeta) of North American crayfishes. Illinois Biological Monographs 17:1–75.

Grabda, E. and J. Wierzbicka. 1969. The problem of parasitism of the species of the genus *Branchiobdella* Odier, 1823. Polish Arch. Hydrobiol. 16:93–104.

Groff, J.M., T. McDowell, C.S. Friedman, and R.P. Hedrick. 1993. Detection of a Nonoccluded Baculovirus in the freshwater crayfish *Cherax quadricarinatus* in North America. Journal of Aquatic Animal Health 5:275–279.

Hanna, G.D. and G.C. Gester. 1963. Pliocene lake beds near Dorris, California. Occasional Papers of the California Academy of Sciences. no. 42, 17 p., 1 fig., 2 pls.

Hanson, J.M., W.C. MacKay, and E.E. Prepas. 1989. Effect of size-selective predation by muskrats (*Ondatra zebithicus*) on a population of unionid clams (*Anodonta grandis simpsoniana*). Journal of Animal Ecology 58:15–28.

Hedrick, R.P. 1995. Impacts of viral diseases on the endangered crayfish, *Pacifastacus fortis*. Progress Report for May 1, 1995–October 30, 1995. prepared for California Department of Fish and Game, Contract DFG 4053 IF, 2 pp.

Hesseldenz, T.F. and M.J. Ellis. 1991. Ecological Survey of Fall River and Natural Gas Pipeline Crossing and Vicinity, PGT–PG&E Pipeline Expansion Project, Shasta County, California. prepared for Pacific Gas and Electric Company, Technical and Ecological Services, 3400 Crow Canyon Road, San Ramon, CA 94583. unpublished report, 42 pp.

Hobbs, H.H., Jr. 1972. Crayfishes (Astacidae) of North and Middle America. Identification Manual No. 9 in Biota of Freshwater Ecosystems. U.S. Environmental Protection Agency, Water Pollution Research Control Series. 173 pp.

Hobbs, H.H., Jr. 1974. A checklist of the North and Middle American crayfishes (Decapoda: Astacidae and Cambaridae). Smithsonian Contributions to Zoology 166:1–161.

Hobbs, H.H., Jr. 1989. An illustrated checklist of the American crayfishes (Decapoda: Astacidae, Cambaridae, and Parastacidae). Smithsonian Contributions to Zoology 480:1-236.

Hobbs, H.H. Jr., P.C. Holt, and M. Walton. 1967. The crayfishes and their epizoötic ostracod and branchiobdellid associates of the Mountain Lake, Virginia, region. Proceedings of the United States National Museum 123:1–84.

Holdich, D.M. and I.D. Reeve. 1988. Functional morphology and anatomy. pages 11–51 *in* D.M. Holdich and R.S. Lowery, editors, Freshwater crayfish: biology, management and exploitation. The University Press, Cambridge, Great Britain.

Holt, P.C. 1967. Status of genera *Branchiobdella* and *Stephanodrilus* in North America with description of a new genus (Clitellata: Branchiobdellida). Proceedings of the United States National Museum 124:1–10.

Holt, P.C. 1981. New species of *Sathodrilus* Holt, 1968, (Clitellata: Branchiobdellida) from the Pacific drainage of the United States, with synonymy of *Sathodrilus virgiliae* Holt, 1977. Proceedings of the Biological Society of Washington 94:848–862.

Holt, P.C. 1986. Newly established families of the order Branchiobdellida (Annelida: Clitellata) with a synopsis of the genera. Proceedings of the Biological Society of Washington 99:676–702.

Lagler, K.F. and M.J. Lagler. 1944. Papers Michigan Academy of Science, Arts, and Letters. 29:293-303.

Lewis, R.H. 1985. Monitoring of wild rice drainage and receiving waters in the Fall River Drainage of California. Central Valley Regional Water Quality Control Board, Redding Office. 44 pp

Lowery, R.S. and D.M. Holdich. 1988. *Pacifastacus leniusculus* in North America and Europe, with details of the distribution of introduced and native crayfish species in Europe. Pages 283-308 *in* D.M. Holdich and R.S. Lowery, eds. Freshwater Crayfish: biology, management and exploitation. University Press, Cambridge, Great Britain.

MacDonald, D.W., editor, 1985. The encyclopedia of mammals. Facts on File, Inc., New York.

Mason, J.C. 1975. Crayfish production in a small woodland stream. Freshwater Crayfish 2:449–479.

McGriff, D. 1983. Growth, maturity, and fecundity of the crayfish, *Pacifastacus leniusculus*, from the Sacramento–San Joaquin Delta. California Fish and Game 69:227–242.

McGriff, D. 1985. unpublished data in California Department of Fish and Game Natural Diversity Data Base, 1416 Ninth St., Sacramento, CA 95814.

McGriff, D. and J. Modin. 1983. *Thelohania contejeani* parasitism of the crayfish, *Pacifastacus leniusculus*, in California. California Fish Game 69:178–183.

Meinzer, O.E. 1922. Maps of the Pleistocene Lakes of the Basin-and-Range Province and its significance. Bulletin of Geological Society of America. 33:541–552.

Meinzer, O.E. 1927. Large springs in the United States. Department of the Interior, U.S. Geological Survey Water-Supply Paper 557:1–63.

Mojica, C.L., J.B. Mire, and D.C. Erman. 1993. The effects of *Pacifastacus leniusculus* on the behavior of the endangered Shasta crayfish (*Pacifastacus fortis*) in an experimental setting. unpublished final report for the California Department of Fish and Game (FG9515), 28 pp.

Moyle, P.B. and R.A. Daniels. 1982. I. Fishes of the Pit River System, McCloud River System, and Surprise Valley Region, *in* Distribution and Ecology of stream fishes of the Sacramento-San Joaquin Drainage System, California by P.B. Moyle, J.J. Smith, R.A. Daniels, T.L. Taylor, D.G. Price, and D.M. Baltz, University of California Publications Zoology 115:1–82.

Pacific Gas and Electric Company. 1993. Draft application for new license, Pit 1 project, FERC no. 2687. vol. I. Pacific Gas and Electric Company, San Francisco, CA.

Pacific Gas and Electric Company. no date. unpublished work orders: PG&E GM–10251; PG&E GM–50128; Canceled-PG&E MR–3915; and PG&E G.M.–85800.

Penn, G.H. 1950. Utilization of crawfishes by cold-blooded vertebrates in the Eastern United States. American Midland Naturalist 44:643–658.

Poore, R. 1995. Clean Water Act 205j Grant Application Draft, submitted June 1995 by Fall River Resource Conservation District, P.O. Box 83, McArthur, CA 96056, 26 pp.

Riegel, J.A. 1959. The systematics and distribution of crayfishes in California. California Fish and Game 45: 29-50

Rickett, J.D. 1974. Trophic relationships involving crayfish of the genus *Orconectes* in experimental ponds. The Progressive Fish-Culturist 36:207-211.

Rose, T.P. 1994. Bidwell Ranch transfer project: geochemical characterization of surface and ground water in the Hat Creek-Lost Creek area, northeastern California, submitted to James C. Hanson, Consulting Civil Engineer, January 4, 1994, 19 pp.

Rose, T.P., M.L. Davisson, and R.E. Criss. 1996. Isotope hydrology of voluminous cold springs in fractured rock from an active volcanic region, northeastern California. Journal of Hydrology 179: 207-236

Russell, I.C. 1885. Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada. U.S. Geological Survey, Monograph no. 11, 288 pp., 45 pls.

Rutter, C. 1903. Natural History of the Quinnat Salmon. A report of investigations in the Sacramento River, 1896–1901. U.S. Fish Commission Bulletin for 1902, 22:65–141, Plates 10–18.

Rutter, C. 1908. The fishes of the Sacramento-San Joaquin Basin, with a study of their distribution and variation. Bulletin of the U.S. Bureau of Fisheries 27:105–152.

Schafer, W.E. 1968. Studies on the epizootiology of the myxosporidan *Ceratomyxa shasta* Noble. California Department of Fish and Game 54:90–99.

Scupman, J.R. 1875. The Pit River Canon. Overland Monthly. December 1875. reprinted in the Covered Wagon, Shasta Historical Society 1982:4–22.

Schulz, P.E. 1990. Road Guide to Lassen Volcanic National Park. Loomis Museum Association, 1990 revision, 40 pp.

Stebbins, R.C. 1985. Peterson Field Guide to Western Reptiles and Amphibians. Houghton Mifflin Co. Boston, MA.

Storer, T.I. 1938. The muskrat as native and alien: a chapter in the history of animal acclimatization. California Fish and Game 24:159–175

Tack, P.I. 1941. The life history and ecology of the crayfish *Cambarus immunis*. American Midland Naturalist 25:420-466.

Taub, S.H. 1972. Exploitation of crayfish by largemouth bass in a small Ohio pond. The Progressive Fish-Culturist 34:55-58.

Taylor, D.W. 1981. Freshwater mollusks of California: a distributional checklist. California Fish and Game 67:140–163.

Taylor, D.W. 1985. Evolution of freshwater drainages and molluscs in western North America. Pages 265–321 *in* C.J. Smiley, editor. Late Cenozoic history of the Pacific Northwest. AAAS, Pacific Division, San Francisco, California.

Taylor, D.W. and G.R. Smith. 1981. Pliocene molluscs and fishes from northeastern California and northwestern Nevada. University of Michigan Museum of Paleontology, Paleontological Contributions 25:339–413.

Unestam, T. 1969. Resistance to the crayfish plague in some American, Japanese and European crayfishes. Institute of Freshwater Research, Drottningholm, Report 49:202–209.

Unestam, T. 1973. Significance of diseases on freshwater crayfish. Freshwater Crayfish 1:135–150.

Unestam, T. 1975. The dangers of introducing new crayfish species. Freshwater Crayfish 2:557–561.

U.S. Fish and Wildlife Service. 1988. Endangered and threatened wildlife and plants; determination of endangered status for the Shasta crayfish. Federal Register 53(190):38460–38465.

U.S. National Park Service. 1974. Lassen Volcanic National Park Environmental Assessment, United States Department of the Interior, 323 pp.

Voegelin, E.W. 1942. Culture Element Distributions: XX, Northeast California. Anthropological Records 7(2):47–251.

von Broembsen, S.L. 1989. Invasions of natural ecosystems by plant pathogens. Pages 77–83 *in* J.A. Drake, H.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmánek and Williamson, eds. Biological Invasions, a global perspective. John Wiley and Sons, New York.

West, D.A. 1969. Pit River Test Hatchery. California Department of Fish and Game, Inland Fisheries Administrative Report No. 69–3. unpublished, 9 pp.

Young, W. 1971. Ecological studies of the Entocytheridae (Ostracoda). American Midland Naturalist 85:399–409.

Personal Communications

Mike Berry, Wild Trout Biologist, California Department of Fish and Game, Redding, California; personal communication on August 23, 1995

Jeffrey Cook, Scientist III, EA Engineering, Science and Technology, Lafayette, California; personal communication on June 19, 1995

Robert Daniels, Ph.D., Curator of Ichthyology, New York State Museum Biological Survey, Albany New York; conducted 1978 surveys for Shasta crayfish; personal communications on April 27, 1993 and June 27, 1995, and letters dated June 18, 1993 and July 13, 1995.

Les Draper, CDFG Pit River Hatchery Manager, Fall River Mills, California. managed the Pit River Hatchery from 1979 to March 1995. He was the second manager at this hatchery. He is now retired and living in Keno, Oregon; personal communications on February 18, 1995 and March 20, 1996.

Mike Drury, Real Property Agent, Land Resources, Pacific Gas and Electric Company, Chico, California; personal communication on February 15,1996.

Leland Kerns, Long-time resident and local historian, Cassel, California; personal communication on August 29, 1994

Ronald A. Hedrick, Department of Medicine and Epidemiology, School of Veterinary Medicine at the University of California, Davis, Davis, California; personal communication on July 11, 1994.

Luna B. Leopold, Professor Emeritus, Fluvial Geomorphologist, Department of Landscape Architecture, University of California, Berkeley, Berkeley, California; personal communication in Dana, California on November 11, 1994.

Rick Poore, Streamwise Consulting, Dana, California; personal communication March 23, 1996.

David Rosgen, Hydrologist, Wildland Hydrology Consultants, Pagosa Springs, Colorado; personal communication in Dana, California on November 11, 1994.

Mike Rode, Senior Biologist, Region I, California Department of Fish and Game, Redding (Mount Shasta), California; personal communication on August 24, 1995

Don Weidlein, Senior Biologist (Marine/Fishery), Region I, California Department of Fish and Game, Redding, California; personal communication on June 19, 1996.

Correspondence

Elliot, Richard L., Regional Manager, Region 1, California Department of Fish and Game, Redding, California, in memorandum dated May 8, 1995 to Tim Farley, Chief, Inland Fisheries Division, California Department of Fish and Game, Sacramento, California.

Grose, T., Fall River Resource Conservation District, Ellis (letters dated December 4, 1996 and May 20, 1997).

Poore, R., T. Grose, and M. Ellis in letter dated June 4, 1997, from Fall River Resource Conservation District, McArthur, California, to R. Sharp of the U.S. Forest Service in Alturas, CA commenting on the Telephone Flat Project in the Medicine Lake Highlands Area.

IV. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows is a summary of actions and estimated costs for this recovery plan. It is a guide to meet the objectives, identifies agencies responsible for performing each task, and estimates total costs for each task. These actions, when accomplished, will satisfy the recovery objectives. Initiation of these actions is subject to the availability of funds.

Priorities in Column 1 of the following implementation schedule are assigned as follows:

Priority 1 - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.

Priority 2 - An action that must be taken to prevent a significant decline in species population/habitat quality, or other significant adverse impact short of extinction.

Priority 3 - All other actions necessary to provide for full recovery of Shasta crayfish.

Key to Acronyms Used in the Implementation Schedule

FWS	=	United States Fish and Wildlife Service
CDFG	=	California Department of Fish and Game
NRCS	=	Natural Resources Conservation Service
RWQCB	=	California Regional Water Quality Control Board, Central Valley Region
COE	=	Army Corps of Engineers
SCG	=	Shasta County Government
PG&E	=	Pacific Gas and Electric Company
CDPR	=	California Department of Parks and Recreation

Key to Other Codes Used in the Implementation Schedule

*	=	Lead agency
Ongoing	=	Task is currently being implemented and will continue until action is no longer necessary for recovery.
Continuous	=	Task will be implemented on an annual basis once it is begun.
TBD	=	To be determined after plans or studies are done or decisions made
Total Costs	=	Projected cost of task from start to completion.

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
1	3.1	Design and conduct flume studies	1 yr	FWS* CDFG	20	20				
Upper Fall River										
1	1.1.1	Work with landowners	Ongoing	FWS* CDFG	1	0.25	0.25	0.25	0.25	
1	1.1.2	Install barrier above Navigation Limit	3 mo	FWS* CDFG	500		500			
1	1.1.3	Restore Bear Creek Meadow	3 yr	NRCS* RWQCB, COE CDFG, SCG	TBD	TBD	TBD	TBD		
1	1.1.4	Enhance habitat	2 yr	FWS* CDFG	1		0.5	0.5		
Spring Creek										
1	1.2.1	Work with landowners	Ongoing	FWS* CDFG	1	0.25	0.25	0.25	0.25	
1	1.2.2	Fortify culverts at Spring Creek Road crossing	Ongoing	FWS* CDFG SCG	16	5	10	0.5	O.5	

Recovery Plan Implementation Schedule for the Shasta Crayfish

						Cost Estimates ($1000)				
Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	FY97	FY98	FY99	FY00	FY01
1	1.2.3	Enhance habitat in lower fish trap cove	1 yr	FWS* CDFG	1	1				
Lava Creek										
1	1.3.1	Work with landowners	Ongoing	FWS* CDFG	1	0.25	0.25	0.25	0.25	
1	1.3.2	Install barrier in east and west arms	6 mo	FWS* CDFG	TBD		TBD			
1	1.3.3	Install barrier at outflow	3 mo	FWS* CDFG	150		150			
1	1.3.4	Eradicate signal crayfish	Continuous	FWS* CDFG	105	25	25	10	10	10
Upper Tule River										
1	1.4.1	Work with landowners	Ongoing	FWS*, CDFG PG&E, CDPR	1	0.25	0.25	0.25	0.25	
1	1.4.2	Assess/install crayfish barrier at Big Lake outflow near Rat Farm	3 mo	FWS* CDFG COE	500		500			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
1	1.4.3	Install barrier at Ja-She Creek bridge	3 mo	FWS* CDFG CDPR	100		100			
1	1.4.4.1	Assess feasibility of barrier at Crystal Cove/Crystal Inlet	2 mo	FWS* CDFG CDPR	30		15	15		
1	1.4.4.2	Install barrier if feasible	3 mo	FWS* CDFG CDPR	500		500			
1	1.4.5	Eradicate signal crayfish	Continuous	FWS* CDFG	190	50	50	25	10	
1	1.4.6	Develop alternatives to dredging to maintain levees	Ongoing	PG&E* COE FWS CDFG	TBD					
1	1.4.7	Enhance and create habitat in Big Lake and Horr Pond	Continuous	FWS* PG&E COE	200		100	50	50	
1	1.4.8	Use native plants to stabilize banks and levees	3 yr	PG&E* COE CDFG	50		20	20	10	

Recovery Plan Implementation Schedule for the Shasta Crayfish

						Cost Estimates ($1000)				
Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	FY97	FY98	FY99	FY00	FY01
Rising River										
1	1.5.1	Work with landowners	Ongoing	FWS* CDFG	1	0.25	0.25	0.25	0.25	
1	1.5.2	Install barrier at Cassel bridge	3 mo	FWS* CDFG	500		500			
Pit River at Sucker Springs Creek (Pit River Hatchery)										
1	1.6.1	Work with landowners	Ongoing	FWS*, PG&E CDFG	1	0.25	0.25	0.25	0.25	
1	1.6.2	Eliminate fish hatchery operations	Ongoing	CDFG* FWS	N/A					
1	1.6.3	Maintain the weir between Ponds 3 and 4	Ongoing	CDFG* FWS	TBD	TBD	TBD	TBD	TBD	
1	1.6.4.1	Restore Ponds 1 and 2	2 mo.	CDFG* PG&E FWS	TBD	TBD	TBD	TBD	TBD	
1	1.6.4.2	Remove Shasta crayfish from Pond 2	1 mo	CDFG* FWS	TBD	TBD	TBD	TBD	TBD	

Recovery Plan Implementation Schedule for the Shasta Crayfish

						Cost Estimates ($1000)				
Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	FY97	FY98	FY99	FY00	FY01
1	1.6.4.3	Relocate Shasta crayfish from Pond 3 to Pond 2	1 mo	CDFG* FWS	TBD	TBD	TBD	TBD	TBD	
1	1.6 5	Eradicate signal crayfish in Ponds 3 and 4.	Ongoing	FWS* CDFG	40	15	10	10	10	
1	1.6.6	Restore habitat in Pond 3	Ongoing	CDFG* FWS	2		2			
1	1.6.7	Install barrier at mouth of Sucker Springs Creek	3 mo	FWS* CDFG	50		50			
1	1.6.8	Eradicate signal crayfish below Pond 3	Continuous	FWS* CDFG	45	10	10	5	5	5
1	1.6.9	Remove barriers between Ponds 1,2,3	1 mo	FWS* CDFG	0.5					

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
Hat Creek, Cassel										
1	2.1.1	Work with landowners	Ongoing	FWS*, CDFG PG&E	1	0.25	0.25	0.25	0.25	
1	2.1.2	Install barrier at Crystal Lake outflow into Baum Lake	3 mo	FWS* CDFG	100		100			
1	2.1.3	Eradicate signal crayfish in Crystal Lake	Continuous	FWS* CDFG	525	65	65	65	65	65
1	2.1.4	Improve land use practices	Ongoing	PG&E* FWS	5	2	2	1		
1	2.1.4.1	Install cattle exclusion fences	3 yr	PG&E* CDFG	TBD	TBD	TBD	TBD		
1	2.1.4.2	Develop protection zones around lakes	Ongoing	PG&E* CDFG FWS	TBD					
1	2.1.5	Restrict fishing at outflow	1 yr	CDFG*	1	1				

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
Sucker Springs Creek (Pit River Hatchery)										
2	1.7.1	Remove hatchery structures and restore streambanks	3 mo	FWS* CDFG RWQCB	120		120			
2	1.7.2	Add lava cobbles and boulders	1 mo	FWS* CDFG	15		15			
2	1.7.3	Evaluate restoration needs	1 yr	FWS* CDFG PG&E	10		10			
2	1.8.1	Remove upstream dam and culvert	4 mo	FWS* CDFG	2		2			
2	1.8.2	Remove upstream sediment	2 weeks	FWS* CDFG	2		2			
2	1.8.3	Add lava rocks and boulders upstream if necessary	1 mo	FWS* CDFG	2		1	1		
2	1.8.4	Evaluate restoration needs	2 mo	FWS* CDFG	1	1				

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
Upper Tule River										
2	2.2.1	Install barriers at cove entrances	6 mo	FWS* CDFG	TBD	TBD				
2	2.2.2	Eradicate signal crayfish	Continuous	FWS* CDFG	100	15	15	15	15	15
2	2.2.3	Enhance habitat	Ongoing	FWS* PG&E, COE	200		100	50	50	
Pit River (mainstem)										
2	2.3.1	Work with landowners	2 yr	PG&E* FWS	1	0.5	O.5			
2	2.3.2	Survey	2 yr	FWS* CDFG	20	5	15			
2	2.3.3	Restore water release	Continuous	PG&E*, FWS RWQCB, CDFG	TBD	TBD	TBD	TBD	TBD	TBD

Recovery Plan Implementation Schedule for the Shasta Crayfish

						Cost Estimates ($1000)				
Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	FY97	FY98	FY99	FY00	FY01
Upper Fall River (invaded by signal crayfish)										
2	2.4.1	Develop management/ restoration plan	Ongoing	CDFG* RWQCB COE NRSC, FWS	TBD					
2	2.4.2	Enhance habitat	Ongoing	FWS* CDFG	5-10	2-4	3-6			
2	2.4.3	Develop plan for site-exclusion barriers	2 mo	FWS* CDFG	52			52		
2	2.4.4	Eradicate signal crayfish	5 yr	FWS* CDFG	15	2	2	2	2	2
2	2.4.5	Monitor nonagency restoration	Ongoing	CDFG* RWQCB NRCS	TBD					
2	2.4.6	Reintroduce or supplement populations	TBD	FWS* CDFG	TBD					

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
Research										
2	3.2.1	Determine food preferences and nutritional requirements	3 yr	FWS* CDFG	10	5	2.5	2.5		
2	3.2.2.1	Determine effects of signal crayfish competition and predation	Ongoing	FWS* CDFG	20	10	10			
2	3.2.2.2	Determine effects of signal crayfish on reproduction	3 yr	FWS* CDFG	10	5	2.5	2.5		
2	3.2.2.3	Determine impact of pathogens from signal crayfish	Ongoing	FWS* CDFG	20	10	10			
2	3.2.2.4	Determine effects of incidental secondary invaders from signal crayfish	Ongoing	FWS* CDFG	20	10	10			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
2	3.2.3.1	Determine effects of fantail crayfish competition and predation	Ongoing	FWS* CDFG	20	10	10			
2	3.2.3.2	Determine effects of fantail crayfish on reproduction	3 yr	FWS* CDFG	10	5	2.5	2.5		
2	3.2.3.3	Determine impact of pathogens from fantail crayfish	Ongoing	FWS* CDFG	20	10	10			
3	3.2.3.4	Determine effects of incidental secondary invaders from fantail crayfish	Ongoing	FWS* CDFG	20	10	10			
3	3.3	Study genetics	5 yr	FWS* CDFG	30	10	5	5	5	5

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
Monitoring										
2	4.1	Monitor success of signal crayfish eradication	Continuous	FWS* CDFG	TBD	TBD	TBD	TBD	TBD	TBD
2	4.2	Monitor status of Shasta crayfish	Continuous	FWS* CDFG	60	6	6	6	6	6
2	4.3	Monitor crayfish barriers	Continuous	FWS* CDFG	45		5	5	5	5
Watershed and Ecosystem Management										
3	2.2.4	Control Tule River muskrat population	Continuous	CDFG* NRCS	30		5	5	5	5
3	5.1	Work with landowners	5 yr	NRCS* CDFG, RWQCB	TBD	TBD	TBD	TBD	TBD	TBD
3	5.2.1	Change crayfishing regulations	1 yr	CDFG*	1	1				
3	5.2.2	Enforce bait restrictions	Continuous	CDFG*	30		30			
3	5.2.3	Prohibit introduction of new exotic species	Continuous	CDFG*	10		10			

Recovery Plan Implementation Schedule for the Shasta Crayfish

Priority #	Task #	Task Description	Task Duration (Years/Months	Responsible Party	Total Cost	Cost Estimates ($1000) FY97	FY98	FY99	FY00	FY01
3	5.3.1	Update irrigation systems to improve water quality	5 yr	RWQCB*	TBD	TBD	TBD	TBD	TBD	TBD
3	5.3.2	Explore effects of agricultural chemicals	2 yr	RWQCB*	TBD			TBD	TBD	
Public Information and Education										
3	6.1	Post signs at boat accesses and public use areas	6 mo	CDFG*	5	5				
3	6.2	Write newspaper articles	Continuous	FWS* CDFG	TBD					
3	6.3	Make public school presentations	Continuous	FWS* CDFG	10	1	1	1	1	1
3	6.4	Provide information at Ahjumawi Lava Springs State Park	Continuous	CDPR	10	1	1	1	1	1

V. APPENDICES

APPENDIX A

Methods For Shasta Crayfish Surveys

The Shasta crayfish surveys that have been conducted since 1990 can be divided into two categories: exploratory and monitoring. Exploratory surveys were conducted to map habitat, substrate, vegetation, and the distribution of Shasta crayfish, introduced crayfish, and sculpin throughout the entire survey area. Many of these surveys were conducted for PG&E as part of the relicensing process for their Pit 1 and Hat Creek 1 and 2 hydroelectric projects (Ellis and Hesseldenz 1993, Ellis 1994a, 1995). Exploratory surveys of the Rising River drainage and other locations that either were not surveyed for PG&E or warranted resurveying were conducted under contract with CDFG from 1994 through the present. Scuba or snorkeling gear was used to facilitate the surveys; scuba gear was commonly used when water depth was greater than about 0.6 meter (2 feet). Surveys were generally conducted by one or two divers and a boat tender. Underwater observations were transmitted to a boat tender who recorded the data on enlarged maps of the survey area traced from aerial photographs or USGS quadrangles.

Rivers and streams were surveyed by two divers whenever possible. Each diver surveyed one-half of the river channel by swimming back and forth between the riverbank and the middle of the river. Work progressed in a downstream direction. Exploratory surveys of rivers and streams consisted of the entire length of the river (e.g., Fall River or Rising River) or of the section of interest (e.g., Hat Creek downstream from the confluence with Rising River). The shorelines of lakes were surveyed by one diver and a boat tender/data recorder. The team would work along the entire shoreline in a single direction. When water clarity permitted clear viewing, substrate and vegetation were also mapped from the boat. All naturally occurring and imported boulder, cobble and gravel areas, including lava spring pools, the immediate vicinity of bridges, and substrate along levees were intensively surveyed by divers. Substrate was identified as silt, sand (rock particles less than 2 millimeters in diameter), sedimentary river gravel (6–40 millimeters), lava gravel (2–75 millimeters in diameter), lava cobbles (75–300 millimeters in diameter), lava boulders (greater than 300 millimeters), lava bedrock, diatomaceous earth/clay, or earthen clumps. Vegetation, molluscs, and most other invertebrates were identified to genus. Rocks were turned over and all crayfish identified to species.

Although crayfish capture was usually not necessary for identification, Shasta crayfish were captured and the following data were recorded for each crayfish: (1) individual size measured as total carapace length (TCL) to the nearest fiftieth of a millimeter with vernier calipers; (2) sex; (3) physical description, e.g., reproductive state, color, missing appendages, general health; and 4) description of habitat, location and behavior. Shasta crayfish were then released next to their rock and coaxed back underneath.

Monitoring surveys were also conducted by divers utilizing either scuba or snorkeling gear. These surveys focused more specifically on the distribution and abundance of Shasta crayfish and introduced species in known Shasta crayfish locations. Crayfish handling techniques were as described above.

APPENDIX B

Flume Study For Testing Crayfish Barriers

Because of the potentially high cost of crayfish barriers, it would be economically prudent to test the design and effectiveness of barriers before installing them. Large scale flume studies should be designed and conducted to test the effectiveness of barrier designs under different water velocity regimes, including no flow (i.e., complete physical barrier), and to determine the impacts of sedimentation and vegetation on barrier effectiveness. To test the effectiveness of barrier designs under different velocity regimes, signal crayfish should be placed downstream of the barrier in the flume while an aromatic bait is placed upstream of the barrier. The flume should be left running for several days, if possible, at each of the test velocities. Different designs for velocity/physical barriers should be tested, ranging from strictly velocity barriers where there is sufficient water velocity to impede all upstream movement of signal crayfish to a strictly physical barrier to block signal crayfish movements in no flow conditions. The effectiveness of the chosen barrier design(s) should also be tested using fantail crayfish under the same velocity regimes.

This velocity regime should include the velocities found at the thirteen proposed barrier sites, which range from the highest flows at the culverts at Spring Creek Road crossing and at Lava Creek outflow, to the no-flow-barriers that would be required to keep signal crayfish from migrating into Big Lake, east and west Tule Coves, Crystal Cove and Inlet, and site-exclusion barriers for the mainstem Fall River subpopulations. Once a barrier design(s) (i.e., modifications on a basic design may be necessary for different flow regimes) is found to be effective, the impact of sediment transport on barrier effectiveness should be tested. It is important to test the design(s) with sediment in the channel (i.e., flume) since sediment could render an otherwise effective barrier ineffective. Similarly, the downstream movement of vegetation and other debris on barrier effectiveness should also be tested.

APPENDIX C

Terrestrial Species with Special Status Within the Range of Shasta Crayfish

Vertebrates

SPECIES	STATUS	
	USFWS	CDFG
Accipitridae (kites, hawks)	None	Species of special concern
Falconidae (falcons)	Endangered : American peregrine falcon (*Falco peregrinus anatum)*	Species of special concern
Greater sandhill crane (*Grus canadensis tabida*)	None	Threatened
Bank swallow (*Riparia riparia*)	None	Threatened
Pale big-eared bat (*Plecotus townsendii pallescens*)	Species of concern	Species of special concern
Sierra snowshoe hare (*Lepus americanus tahoensis*)	Species of concern	Species of special concern
White-tail hare (*Lepus townsendii*)	None	Species of special concern
Sierra Nevada red fox (*Vulpes vulpes necator*)	Species of concern	Threatened
Pacific fisher (*Martes pennanti pacifica)*	Species of concern	Species of special concern
Wolverine (*Gulu gulu*)	Species of concern	Threatened

Plants. PG&E conducted a literature and herbaria review to determine whether any special status plants could potentially occur within the project boundaries of the Pit 1 and Hat Creek projects, as part of their relicensing process. None of these species were observed during PG&E's surveys of the Pit 1 Project vicinity. There were no records of any special status plants occurring in the midsections of the Pit River drainage according to the California Natural Diversity Data Base (CNDDB) or the California Native Plant Society (CNPS).

SPECIES	STATUS		
	USFWS	CDFG	CNPS
Long-haired star tulip (*Calochortus longebarbatus* var. *longebarbatus*)	Species of concern	None	Rare, threatened or endangered in CA and elsewhere
Mathias' button celery (*Eryngium mathiasiae*)	Species of concern	None	Plants of limited distribution
Boggs Lake hedge-hyssop (*Gratiola heterosepala*)	Species of concern	Endangered	Rare, threatened or endangered in CA and elsewhere
BellingerMeadowfoam (*Limnanthes floccosa* spp. *bellingeriana*)	Species of concern	None	Rare, threatened or endangered in CA and elsewhere
Egg Lake Monkeyflower (*Mimulus pygmaeus*)	Species of concern	None	Rare, threatened or endangered in CA and elsewhere
Slender Orcutt Grass (*Orcuttia tenuis*)	Threatened	Endangered	Rare, threatened or endangered in CA and elsewhere
Western Campion (*Silene occidentalis* spp. *longistipitata*)	Species of concern	None	Plants about which more information is needed

DATE DUE
